NOTES ON CHEMICAL RESEARCH

TEXT-BOOKS OF CHEMICAL RESEARCH AND ENGINEERING

NOTES ON CHEMICAL RESEARCH

AN ACCOUNT OF CERTAIN CONDITIONS WHICH APPLY TO ORIGINAL INVESTIGATION

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PREFACE TO SECOND EDITION

The text of the first edition has been considerably enlarged, and the present volume is divided, for convenience, into two parts. In the second will be found an account of works practice and organisation which conforms to the requirements of modern research. A chapter has been added on the somewhat vexed question of the student's training.

The writer believing, that, if a similar book had been placed in his hands when he left college, he would have reaped an advantage, now passes this one, in its present form, on to the student.

THE AUTHOR.

PREFACE TO FIRST EDITION

MODERN science is based on the record of past investigation. This condition must therefore apply to chemistry, which is essentially an experimental science.

While original investigation remains an important factor in further progress, those engaged in any branch of science must have some knowledge of the general conditions under which such work has been undertaken in the past; and realise that it can only be undertaken by an investigator who has reached a stage in his development, at which he is able to think in terms of his science. He must become one with his work.

A mere knowledge of facts and principles, however complete in itself, is an insufficient equipment. A student may possess this, and yet occupy an isolated position. Many who seem well qualified by examination, or otherwise, fail in the initiation of such work, for they cannot make practical use of such knowledge and apply it to the further investigation of natural phenomena.

Other important conditions are involved in work of this nature. They are of little account in the absence of this controlling factor, which brings with it the power of *seeing into things* and realising the relative importance of observations made under definite conditions, and the correctness, and value, of any deductions arising from the same.

An attempt has been made to state, in general terms, the conditions which have been regarded as

essential to success. The influence and importance of the results already obtained by investigation have been generally noticed, and the recent advance in the conditions of training and facilities for research has not been overlooked.

The student must give special attention to the theoretical side of his science, and train his mind to discover in the recorded work of others, the conditions which have led to success; examining the why and wherefore of each step, as it occurs in its natural, and therefore logical, sequence.

Such intangible factors as mental outlook and personal qualifications can only be dealt with in a general way, and then chiefly by reference to the experience of past investigators. It is equally difficult to determine, from available data, to what extent these faculties may be developed, or actually created by training. It is certain, however, that when these are present, the battle has yet to be fought out in the laboratory, or works.

An insight into such matters may be gained by examining the results obtained by others. A general knowledge of the conditions involved must be possessed by those who wish to succeed in the conduct of such work. In some cases a survey of past investigation may be the simplest way to secure this end. A search of this nature will often suggest the need for further investigation, and supply the investigator with suitable subject-matter for research. This end may also be secured by the study of abnormal phenomena, which may from time to time be observed in actual practice, particularly when these occur on an industrial scale.

A satisfactory knowledge of the conditions which govern such investigation is of importance to the general chemist. It cannot fail to influence the conduct of routine work, and instil into it a new meaning.

Generally speaking, the laboratories of our leading colleges and technical institutions offer facilities for the conduct of such work. When these are examined and considered, in conjunction with those which exist elsewhere, it is evident that still more attention will be paid to investigation of this nature. This must greatly influence, if not determine, the future of our industries, as well as our position in the scientific world. That this fact is being more and more realised is sufficiently obvious.

It is hoped that the publication of this small work may induce the student to realise certain essential conditions which must necessarily govern his future work, and emphasise the value of those personal qualifications which can be recognised as influencing the work of investigators in the past.

THE AUTHOR.

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?ART I.—SCIENTIFIC FACT AND METHOD

" *When man dropped the idea of concealing knowledge, hemist gave place to chemist, and all that is worth having in dern life, all that makes it better and safer and more hopeful n the ancient life began.*"—H. G. WELLS.

CHAPTER I

NATURE OF SCIENTIFIC KNOWLEDGE

"*The chymists are a strange class of mortals impelled by an almost insane impulse to seek their pleasure among smoke and vapour, soot and flame, poisons and poverty, yet among all these evils I seem to live so sweetly, that may I die if I would change places with the Persian King.*"—Physica Sunterranæa.

General Knowledge.—Our knowledge of the natural phenomena known to chemistry, and the experimental sciences which have sprung from the latter in the course of its development, is confined within the range of our senses. In certain cases, this natural limit has been extended by the aid of instruments of precision, such as the spectroscope or microscope. The application of mathematics, when applied to the extension of knowledge has served a similar purpose.

The results obtained from a study of the conditions which control, represent, or indicate, in accepted terms, such changes or phenomena have been brought to a state of order and expressed in terms of so-called laws. In this way, many phenomena have been reduced to terms of definite comparison. A classification of the results thus obtained provides that the work of the past is under continual revision, and re-examination in the light of further discovery.

It is not possible to determine how far the conclusions arrived at correspond with the ultimate conditions of energy and space; or whether these can be satisfactorily expressed in terms of our system of thought. Facts and phenomena, as we

realise them, may be so distorted in their expression or so partial in their nature, that the conclusions arrived at may only outline actual fact as a shadow on the wall represents the substance.

There is, however, a growing sense of security in the value of modern methods of research, and a belief that these indicate, in some way, the nature of natural phenomena, even if they still fail to represent it in absolute terms. This conviction is based upon the nature of the evidence brought forward by the practical investigator.

A hypothesis is accepted, and its use becomes general, when it offers an explanation of certain phenomena. It is specially received when its use is a general one. It must always be remembered that the hypothesis is a "mentally constructed and quite imaginary mechanism," and that it may not in any way represent the actual conditions existing in nature. All that can be said is that it would appear to be true, and that it is a useful aid in practical investigation.

In the scientific examination of natural phenomena, the research is carried to the point where for the time being further progress seems impossible, and where provisionally the results and generalisations secured are regarded as representing knowledge. An atom was so regarded until it was resolved into simpler units. The latter, in their turn, remain for the time being the accepted foundation of what is termed matter.

Experimental Science.—An experimental science may be stated to be developed in relation to its power of direct measurement, that is to say, in the expression of its conclusions in quantitative terms. This explains the importance of some new scientific instrument, which enables us to increase knowledge on a quantitative basis. Such an in-

strument may have a great value in its application. An example of this might be seen in the receiving instrument in a wireless station where the exact record is obtained by the receiving of rays of certain wave length.

The limits of scientific inquiry are quite definite. Science is concerned with the question *how* things take place; it has never, in a single case, been able to explain *why*. There is no indication that we shall ever be able to answer the latter question. The first cause is unascertainable, and will probably remain so. To appreciate the why and wherefore of things, we should have to get outside our present system. This seems to present an impossible condition. The only alternative is that knowledge should come from the outside. Even then it is doubtful whether this could be expressed in our method of thought, which is so closely founded upon our own impressions.

In the search after *causes* there is a distinct break in our experience. The former are beyond experience and thought. The curtain is down, and there is no certainty that it will ever be lifted.

Uncertainty as to ultimate conditions need have no disturbing influence on the student's mind, as to the value of the experimental method. Rather may the contrary effect be produced. The future programme before the chemist is sufficiently definite. Investigation must be continued and extended in every possible direction by the aid of experiment, carried to its utmost limit, and then compared with the results obtained in other branches of science.

Knowledge gained by the aid of experiment is said to have been obtained by a process of induction. This may be, within certain limits, utilised to a further extent by a process of deduction. The attempt to extend knowledge on lines of theory by considering the nature of results which may reason-

ably be expected to follow under conditions equivalent to, or in extension of, those already dealt with, has been shown to have a definite value.

By this method of reasoning future results may be anticipated; results (inferred or foretold by such speculation) arrived at, and important conclusions obtained. The existence of unknown elements and their properties have been deduced and subsequently verified by experimental evidence.

Such deductions have been shown to be fully justified as a means of progress. Conclusions based upon theory have been of considerable value as stepping-stones to a further advance, or the bridging in a temporary way, of gaps in the chain of experimental evidence.

Direct and Indirect Knowledge.—At the same time a sharp line must be drawn between knowledge obtained by direct and indirect methods, which may be defined as of the first and second order respectively. When an investigation is based on theoretical speculation, the results obtained must be of a convincing nature. They must be continually subjected to re-examination in the light of further experimental evidence and compared with any new facts, which may support, or oppose, the conclusions originally arrived at.

The student will always remember that a so-called fact is of no value except in its relation to other facts, and that as the latter are multiplied, or varied, its significance will be correspondingly changed.

In the absence of any definite plan of action, a preliminary scaffolding, based on theory, may sometimes be erected. When the experimental results obtained do not conform to, or uphold this, it must be correspondingly modified, or replaced by one which agrees with further facts disclosed to the investigator.

Such a use of theory is fully recognised. It serves a purpose by indicating new lines of research, which the results obtained by the investigator must either prove to be of value, or the reverse.

A hypothesis is defined by Mill as a supposition which may be made without actual evidence, or on evidence avowedly insufficient, in order that an attempt may be made to deduce from it conclusions in accordance with facts which are known to be true. When a hypothesis becomes well established it is regarded as a working hypothesis.

Where a general relationship is observed, as in the distillation of dilute solutions of fatty acids, where a definite relationship between rate of distillation and molecular constitution can be traced, such results are conveniently referred to as regularities.

The relative value of induction and deduction has been much discussed. The successful investigator must be prepared to make use of both methods, verifying all deduction by direct experiment (where this is possible) as the research opens out and progresses towards its logical conclusion.

Chemical research is confined mainly to the study of changes which matter undergoes under definite conditions of strain, with an examination of products obtained, and the conditions ruling at the time. The examination is completed by the setting out of results in terms which suitably classify them.

A record of such facts has been defined as "crude knowledge," which, in turn, may be regarded as the raw material of science.

In economic research, a search is made for the conditions which give greatest efficiency and the easiest methods of working which are consistent with the same.

Classification of Knowledge.—Knowledge is either generalised, or empirical. In the latter case it has

not yet been expressed in terms which can be recognised, or referred to any known cause or law. Facts of this nature are considered useless for the purpose of science, although they may have a definite value in the arts and manufactures. Where these exist there is a further call for an investigation of recognised conditions. Many pay special attention to these reactions, for they often suggest suitable subject-matter for further research. In the industrial world such phenomena are constantly met with—in many cases to be lightly passed over. Thus promising material for research is too often neglected for want of a suitable opportunity for investigation. As this undesirable position is met with in the works rather than in the laboratory, it is still prevalent in many directions. Under the stress of circumstances or through neglect, the connecting link between the passing observation and the means of examining it in detail is absent.

Stages of Discovery.—It is doubtful whether the terms "pure" and "applied" research still serve a useful purpose. It is therefore suggested that these be replaced by "static" and "dynamic."

Under modern conditions, there is no real distinction between the methods employed in the different branches of research. A worker should be able to engage upon academic, or practical research with equal success, especially if any training he may have received in method has been supplemented or based upon a real knowledge in the underlying principles, which necessarily control practice. The aims of the workers may differ, but the underlying principles involved are of the same order. It is held that the main consideration is whether the results obtained are useful. If so, the process of discovery is complete. To call research "pure" when it yields results which constitute crude

knowledge, as it is termed, and "applied" when it yields knowledge which is immediately useful, is beside the mark.

If, however, knowledge is regarded as static until discovery is completed, and dynamic when this stage is reached, difficulties in classification are reduced or eliminated, and the additional recognition, which research should receive when it is of economic value, is secured.

During this first stage of discovery, knowledge remains static. When by further discovery, or action, it is brought into the region of usefulness it becomes dynamic. Thus discovery is completed and "crude knowledge" becomes useful knowledge, and a further advance in experience is secured. In a certain class of research, knowledge becomes dynamic at an early stage of discovery. This happens when the investigation is practical.

A generalisation may come as a flash, or by a long-drawn-out process entailing close investigation. In the first case, it must agree closely with observed fact, or else tested for its validity, by the carrying out of further investigation, which will either support, or destroy it.

During this process, uncertain facts and theories are rejected, and thought crystallises into more convincing explanations. A final stage is reached, when observed facts seem to conform to the suggestion that the principle exists.

Nature of Discovery.—Every time a new substance is prepared, or a new discovery made, a further step is taken in the development of science. Yet in the former case every link in the chain was present before the investigation was started, and action would have resulted in precisely the same manner had the new conditions been normally present in nature.

When the knowledge so obtained can be utilised

in an economic sense, it stands on a higher plane. When its nature is such that it leads to the production of a new instrument of precision, or a new generalisation, which materially simplifies practice, or when it aids progress in some other way, knowledge takes to herself the mantle of usefulness, its highest attribute.

In the absence of an immediate use, knowledge must be recorded so that it may be available should some new conditions arise, making possible its utilisation.

Generalisations and Laws.—The validity of a law is based upon the assumption that a phenomenon is always determined in exactly the same way, and that the relation between an observed fact and the conditions which give rise to it, is always the same.

When observation proclaims an ordered sequence, it is necessary that the conditions, which give rise to the observed phenomena, should be discovered by experiment.

When a generalisation is observed, it is sometimes very difficult to determine how far it applies in nature, for in some instances it may be cloaked by simultaneous action of another order. Thus, while it is far easier to burn straw than a piece of iron, yet if the latter be finely divided this order is reversed.

Utility of Scientific Knowledge.—The statement is often made that knowledge obtained by scientific method will, sooner or later, be of value. This may be so in well-considered research, but it is evident that much of our modern work will not stand the test of time, especially when it is based upon imperfect data or theory. It is also evident, that of the many thousands of substances, which have been prepared, a very small proportion can possess such distinctive properties that they will have an economic value.

The only way to overcome this difficulty is to work in practical directions.

That research of the right kind will be useful in the long run is illustrated by the following instance. Twenty-five years ago two enthusiastic collectors amassed a collection of fleas from all quarters of the globe. These were carefully classified and described. Many years later, it was discovered that fleas were carriers of bubonic plague from rat to man. The original work then became useful, to those who were engaged upon the major research, as it shortened the time taken, and provided useful information.

It is doubtful whether a similar use will be found for much of our modern research, which carries with it indecision, mainly due to an imperfect realisation of the aims of research, and the guiding principles which must rule its action.

The worker, who possesses the instinct, which leads him to proceed in useful directions, is distinctly favoured. The results he obtains bear the impress of usefulness, and gradually his fellow workers look for accounts of his further work with increasing interest. When investigation is distorted, or apparently aimless, or where it merely has a reflected interest, it has less value than some simple piece of works practice, which has been carried out with a definite end in view, and in accordance with the rules governing scientific investigation. The latter is straightforward and practical, the former mechanical and indefinite.

The chemist should therefore see to what end his work will lead him. If this is indefinite or ill-considered, the results may be equally unsatisfactory. When it is seen that a definite end is unlikely, the original scheme should be remodelled or discarded. There is little advantage in planting seed in a wilderness when there is unoccupied ground of high fertility available.

Only that section of research which is practical, can

influence current ideas. The rest is shelved because its value is too indefinite, and there only remains the prospect of it becoming useful in the future.

Research based upon practical ideas can never be trivial. When it is simple in its nature, it is often purposely so. Those who have vision, a wide outlook, and the faculty of realising the things which really matter, always give a practical turn to their work.

Limit to Experimental Knowledge.—The difference between the "how" and "why" of things is apparently fundamental. This is well illustrated by the recent discovery that light is subject to the action of gravitation, and deflected in its passage by a solar body. This discovery, great as it is, does not extend to that realm of knowledge which must deal with the reason why gravitation exists. Conceivably the solution of this represents the next stage of discovery, but at present there is no evidence that this will be brought within the range of human experience. Evidence that this knowledge can be obtained by the experimental method is entirely absent, nor can we guess at the means which would bring it within our ken.

All that we can be reasonably certain of is that, by following the present road of experience and thought, a former basis of knowledge may be established. Where the end of this journey will find us is a matter of speculation. Apparent contradictions cannot be cancelled out, and their existence may either point to imperfect views and methods, or to the fact that we are approaching the limit of experience.

Of one thing we are certain. Experimental evidence is the only safe guide to progress, and that, at its best, science is nine-tenths practice. At present we observe empiricism at one end of the scale, and relative knowledge at the other, and between

these two extremes actual practice. We can explain *how* things act, but never *why*.

The Unknown.—Speculation of the above order naturally leads to inquiries as to the nature of the unknown. One school holds that this is merely an extension of the known, and that our methods will gradually carry us into this region of knowledge. The other holds that the unknown, as represented by the why of things, is of a different order, and may always remain outside the range of human thought and experience, through the fact that we are part of the system which it is sought to realise.

It is increasingly difficult to resist the conclusion that research only results in relative knowledge. This being so, it follows that its value must be expressed in terms of practical utility, rather than absolute truth.

Its usefulness depends upon the fact that the knowledge obtained is gained, by experiment, and that it can therefore be utilised on economic lines.

Extension of Discovery.—The further effect of discovery is well illustrated by the results which have followed the recognition of the existence of electrons. The infiltration of this knowledge has recently led to the belief that in their action an explanation of the mystifying results obtained by catalysts is obtained, and possibly the similar effects produced by enzymes is also due to radiation, and its influence on the surrounding molecules. If this is so, many hitherto unexplained phenomena can be traced to their action. Thus a real discovery of a practical nature may, by further discovery, become of increasing utility, and bring advantage in unexpected directions.

The fact that a single molecule of barium sulphate will influence ten million molecules of water, so that they are incapable of dissolving other barium

sulphate molecules, and that this single molecule may greatly modify the conductivity of the water, similarly point to the widely set action of a second substance. While the explanation of this phenomenon is unknown, it has been recently suggested (Bacon, J., *Physical Chem.*, 1919, **23**, 469) that the increased conductivity may be due to the barium sulphate molecule splitting up into an enormous number of electrons, each possessing the characteristic periodicity of the parent molecule, and that these permeate the solvent so that each molecule of the latter comes in contact with these electrons periodically at least, and that by such means an equilibrium relation is maintained.

As in the case of the dissociation theory, it is obviously necessary to assume a force exerted by the solvent molecules, which is capable of overcoming the molecular force holding the solute system together; so in extremely dilute solutions, like the one mentioned, the secondary attraction between the molecule of solute and those of the solvent may play a similar part to that suggested to explain the isolation of atoms or ions in solutions, and thus the system suggested for the latter possibly may be extended to the electrons themselves.

The re-examination of past knowledge in the light of more recent discovery must be continuous, and the effect of this on current fact is observed. The relativity of knowledge is thus emphasised, also the fact that every new discovery of importance reacts in its influence upon other fact. In the presence of a new fact, past knowledge becomes strained, and ideas only settle down when it is fully ingested, and knowledge tuned to the new conditions.

Nature of Experience.—The message brought by travelling light indicates that we are surrounded by immeasurable distances, and that the solar bodies

are of similar composition to the earth. That the solar bodies are set with enormous intervening distances of space, resembling on a magnified scale, the setting-out of the molecules, atoms and electrons in the molecular system.

To appreciate distance, it may be remembered that this earth would take a thousand years to travel round the sun, if it progressed at the rate of sixty miles an hour. This distance is actually performed in one year. A student of twenty will have already travelled eleven billion miles on this comparatively restricted journey without realising it.

The stars in the " Milky Way " are three thousand light-years away from the earth, yet light travels at the rate of 186,000 miles a second. One hundred and eighty million stars have been photographed.

At the other end of experience, we have the results obtained by the use of the ultra-microscope, or the apparatus used to track and weigh a single electron.

Such terms of reference indicate conditions so diverse and extreme, that they cannot be realised by the side of the measurements we are accustomed to in everyday life. On such a basis of comparison the latter hardly seem to exist. Yet they occupy our main attention. Thus we are able to realise the relative physical significance of these greater, and smaller, measurements, and to observe that apparently there is equal perfection in the infinitely great and the infinitely small.

In the midst of such amazing conditions the chemist works at his bench, and plays a part which is extraordinarily diverse.

By the methods of scientific control he leads nature to work in new directions and utilises, to his own advantage, the effects produced.

This leads him to claim a very definite recognition for his science. From a plane on one of the smallest

solar bodies he perceives inexorable law and order in the infinitely great and the infinitely small, and observes that there is no apparent break in the system, which yields to his observations.

Science founded on Definite Procedure.—Chemistry is founded upon relative measurement or action. It follows that all who work in this science should have a clear idea concerning the underlying principles which govern these, and give to chemical research its meaning and direction. In the absence of such knowledge, progress will be delayed, and the results obtained less definite.

Much information may be gained by watching others when they are engaged upon scientific research, but this must always be an incomplete experience in itself. The great masters did not gain their powers by such means, but by personal effort.

A navigator more nearly reaches his destination when he sails over a beaconed course, than when he passes over uncharted seas. So in practical research there are equivalent means of securing a rapid passage from the known to the previously unknown.

The aim of the scientific worker is such that his endeavours are inspired by ideals, rather than prejudice. The alchemist worked through mystery and isolation, the chemist works in the market-place. The one sought the shadow, the other seeks the substance, the first led to uncertain fact and sometimes trickery, the second to useful knowledge.

CHAPTER II

HISTORICAL REVIEW AND NATURE OF RESEARCH

"*A genius is the most indispensable instrument of material or mental progress.*"—CHR. COLLIN.

Review of Past Investigation.—Chemistry, as an exact science, dates back to the middle of the seventeenth century, although it has been practised for thousands of years in a purely empirical manner.

It is thought to have originated with the manufacture of alcohol by a process of fermentation, and the natural control of such operations ("History of Chemistry," Thorpe, 1909). This substance is said to have been manufactured in China in the year 2220 B.C. Dyeing, the production of leather, the working of metals and alloys are also of great antiquity. There is evidence that these operations were conducted with skill by the Egyptians from very early times.

The speculations of Jean Rey, in France, and of Descartes, foreshadowed the birth of systematic investigation.

In this country research may be said to date from the formation of the Royal Society, and the immediate results which led up to this important event. In 1661 Robert Boyle published the "Sceptical Chemist," in which he outlined a new philosophy. This investigator, with the help of certain supporters, sought to cultivate the system which naturally followed on his suggestion. The Invisible College, based on a conviction that "there was no certain way of arriving at any knowledge unless they made a series of experiments upon natural bodies," was

founded. Boyle's personal work at once set a high standard for future investigation. A consideration of his discoveries, experiments and conclusions, is of absorbing interest to the student. His conception of an element is in general use to-day; but his great service to science and learning consisted in the new spirit he infused into chemistry, which at once lifted it into the plane of a great science. It no longer remained the handmaid of medicine, as it had formerly been.

As a result of this vital change in method, chemical research was seen to offer great possibilities, and the Invisible College became the Royal Society, the charter of which was obtained in 1662.

Robert Boyle's conclusions were destined to influence the entire scientific world, as well as to give rise to modern chemistry. To the close ring of mere thinkers the experimental basis of science was first proclaimed, and then established.

An examination of Boyle's work brings with it a certain realisation of a power of concentration and determination, which are present in all important work. Its lasting influence emphasises the importance of knowledge, as this is based on direct experiment, and indicates the respect which such work must always command. It shone out as a bright star from a firmament of make-believe. It still remains as an example to those who have the advantage of working under modern conditions. Boyle's method has dominated research and become the recognised basis of all scientific inquiry.

Boyle certainly owed much to the teaching of Francis Bacon, that greatest of the Moderns. He carried out in his work, the principles enumerated in "Novum Organum." Bacon fought against the *à priori* method of establishing the first principles of any science, and then by syllogism the propositions which that science could contain. Bacon was so

followed as a direct result of the general acceptance of this idea, the student will at once realise the supreme power and value of research, and measure its direct influence on the progress of civilisation. The suggestion of continual progress must be the underlying thought. It must guide the investigator at all times and find expression in any research having a permanent value. Progress by research has become the watchword of science, and is rapidly occupying an equally important position in the industrial world.

The historical side of this development may be followed in "The History of Chemistry" by Sir Edward Thorpe (1909). This, with its excellent bibliography, forms a suitable introduction to the subject. For further details the standard works may be consulted. The student should also be acquainted with the Alembic Club Reprints and Ostwald's "Klassiker."

Advance by Successive Stages.—The determining phases of the advance of chemistry are many, but the following discoveries roughly set out the beginning of new things and the features of research which have most deeply modified this science :—

(1) The period up to 1869 during which many elements had been discovered and isolated, and their properties observed and compounds prepared from the same.

(2) The periodic system of Mendeléeff (1869), following on the preliminary work of Newlands in 1864.

(3) Atomic Grouping by Kekulé (benzene ring) (1865).

(4) Law of Mass Action by Guldberg and Waage (1867), following on the work of Wenzel (1777), Berthollet (1799), Wilhelmy (1850), and Berthelot (1862).

(5) Thermochemistry, study of, by Thomsen (1860), Berthelot (1865).
(6) Stereochemistry: Pasteur (1850), Le Bel (1874), and van't Hoff (1874), and Guye (1890).
(7) Phase Rule: Gibbs (1874).
(8) Osmotic Pressure: van't Hoff (1894), following Pfeiffer's work (1877).
(9) Electrolytic Dissociation: Arrhenius (1884), following Clausius (1851), and Grotthaus (1806).
(10) Theory of Solution: van't Hoff, Arrhenius, Jones.
(11) Radioactivity: Crookes, J. J. Thompson, Röntgen, Curie.

It is claimed that chemistry first became an exact science as a result of certain generalisations, the first of which was the law of mass action. This is, of course, the view of the physical chemist. It is not possible at the present time to estimate the respective value of these epoch discoveries and of others which have not been included in this list, but the mere recording of them indicates at a glance the nature of certain researches, which have become classic as a result of their far-reaching influence.

v **Present State of Research.**—When considering the exact position of research, the beginner must guard against the conclusion that startling discoveries result from a casual observation on the part of some investigator. This is not so, as many previous investigators must have overlooked these same phenomena. Only a trained observer can appreciate their significance, and take advantage of their occurrence.

Under modern conditions, successful investigation has its origin in close reasoning, and only when this is accompanied by a careful survey of previous work,

and a full consideration of the best conditions of working, can a successful issue be anticipated.

This view was certainly held by Faraday. When referring to his own experience he said "that the world little knows how many of the thoughts and theories that have passed through the mind of a scientific investigator have been crushed in silence and secrecy by his own severe criticism and adverse examination, that in the most successful instance not a tenth of the suggestions, the hopes, the wishes, the preliminary conclusions have been realised."

Thus, it is generally held that no scientific discovery can, with any justice, be considered as due to accident; previous knowledge and training are essential before results worthy of consideration can be secured, or, what is perhaps of more importance, their true significance realised. The young investigator will do well to accept this statement. It is important to realise from the first that discoveries are laboriously sought for; that they are the result of a direct and patient search. Having realised this, false hopes are destroyed, and additional value is given to the results obtained. This belief will act as an incentive to the student to make full use of facts already available, and to attempt to increase knowledge by his personal endeavours. It points to the only practical means by which success can be assured.

"Accidental" Discovery.—Exception has been taken in some quarters to the opinion expressed in the last paragraph, which was first emphasised by Gore. It is true that many cases can be cited, where it would appear at first sight that important results have been secured by accident. A detailed examination will bring to light the fact that the discovery was only apparently accidental. The presence of unsuspected conditions had been seized upon by the investigator, with a result that the research took a

modified direction. By such means progress has undoubtedly been hastened.

A broken thermometer introduced mercury into the sphere of action in the preparation of one of the intermediate compounds in the production of synthetic indigo, with beneficial results. Yet only the methods of exact experimenting brought the cause of the effect produced to the surface, and it is known that the search for the increased efficiency observed was a long one, and the tracking down of the real facts was an exhausting process. The closest methods of reasoning and experiment were required.

It is commonly stated that Perkin discovered mauveine by accident. Yet Emil Fischer spoke of this discovery in the following words: "While examining the impure aniline available at this date he was led to try the effect of oxidising agents on the same. He was instantly rewarded with an uninviting purple precipitate, which most of the chemists of his day would have thrown into the sink. Yet such was his perseverance that from this unpromising product he was able to prepare the first protean series of coal tar dyes."

The nature of this accident is thus disclosed. It is seen that the main factor was the personal action of the investigator, who by skill and perseverance followed up his work to its natural limits. The production of a dyestuff was unexpected, just as the discoveries of Faraday could not have been anticipated by mere surmise. The point to be emphasised is that the search must be a true one, and that the full powers of a skilled investigator must be brought into play, and all the laws which govern investigation given full consideration. Then alone will determining results be obtained. In practically all cases the discovery comes to the qualified and skilled observer. To call this accidental is a misuse of words.

The account given by Kekulé concerning the discovery of his benzene theory is another case in point. The final result followed an intense search.

It must follow therefore that an accidental discovery, should this exist in very special cases, must stand on a lower plane to one that is definitely sought for, or directly obtained by the highest skill and foresight.

A good example of the latter is found in the case of salvarsan. Here a deliberate search for a compound, which would possess in addition to certain properties another one which would make it useful in a new direction, was carried out. The thorough nature of this search is revealed by the statement that 605 compounds gave negative results before one was secured, which possessed the combined properties which were looked for. It has been stated that some sixty chemists were engaged on this search.

So-called accidents therefore resolve themselves into occurrences the significance of which is only realised by those who are able to grasp the truth, lying behind the observation.

The student will do well not to rely upon accidental discoveries; far less to get in the habit of working for them. He must accustom himself to a definite search for knowledge by investigation, governed by certain definite rules. He must regard the results, not as accidental, but as arising directly out of his work.

As quoted elsewhere, Crookes held that a scientific observation was lost upon any but the skilled investigator, and that it simply did not exist to others. Empirical knowledge may be accidentally acquired, but scientific knowledge never. The fundamental basis of such research is order, not accident.

The recognition of this fact is of considerable importance to the routine worker, for it indicates that there is always a reasonable chance of securing results by close observation. In standard methods

of analysis the only safe means of detecting remaining errors, or inherent defects, is by a comparison of the results obtained on constant repetition. This often leads to improvements and modification in detail. Such results become immediately useful. They may even, as in the past, bring to light new problems of a comprehensive nature, and lead to further investigation on more general lines. Thus each type of worker has special opportunities for securing an increase in knowledge, which may be obtained in this case by applying the latest methods of experimental investigation to the everyday operations of the laboratory.

In experimental investigation great attention must be given to detail. Where this is not fully realised, conclusions will be drawn from premises, which are either incomplete or incorrect. When such conclusions are made further use of, confusion and uncertainty must follow.

Special Requirements of Economic Research.—In large-scale operations a false step may be disastrous. Much time has been lost in attempting to apply imperfectly worked out processes on a manufacturing scale. The effect on the actual investigator of such partial success, or failure, is equally unfortunate, as it may lead to a corresponding lack of confidence in his ability to carry out such work in the future.

The natural difficulties, surrounding an attempt to increase the scale on which an operation is conducted, are always formidable. The data obtained in the laboratory under the best conditions are often not sufficiently complete for such an extension to be carried out without further investigation. New difficulties come to the surface, which have to be overcome by further research in the works.

All possible care therefore must be exercised in the initial or laboratory stage, and the results examined

and checked in the smallest detail. In this way the presence of difficulties introduced through want of knowledge can be reduced to a minimum.

The need of a sound training in the methods of conducting research is self-evident. It is an essential condition to success. The only point remaining for discussion is how such training can be imparted to a student in the university or college.

Definition of Research.—Experience has shown that it is difficult to define the exact nature of research.

It has been defined as a "wrestling with nature, a striving towards a limit of attainable knowledge." In putting forward this definition, Gore held that it consisted of observation, study, and experiment, in varied proportions.

Discovery has generally been defined as "a passing from the known to the unknown." It is considered that this result is achieved in the following instances:—

(1) When we perceive a new impression.
(2) When we observe a new fact.
(3) When we compare two ideas and observe a new similarity, or difference.
(4) When we compare two propositions, and perceiving a similarity, or difference, infer a new truth.
(5) When we divide, or analyse, a compound idea, and perceive a new, or more elementary one.
(6) When we combine two or more ideas together by an act of imagination and perceive a new combination.
(7) When we permutate, or alter, the order of a series of ideas, and perceive a new order.

When an attempt is made to define the exact relation between observation and research it is difficult to arrive at a satisfactory result. The

following definition, recently set up to meet special conditions, suggests, by inference, the nature of such differences :—

It is considered necessary that :—

(1) Research as the result of observation, or experiment, must result in the collection of new facts.

(2) It must involve an examination of the facts collected or phenomena observed, and their reduction to a form in which they constitute an addition to knowledge.

W. M. Gardner has defined research as "a logical and original investigation inspired by imagination and directed by special knowledge."

Chemical research has been divided into two distinct branches, which deal respectively with investigation, which has theoretical or practical significance. Sir William Tilden has summarised these respective spheres in the following terms :—

(1) The worker watches the operations of Nature and puts questions in the form of experiments solely with the desire to find out her ways.

(2) Attention is given only to those laws, facts, and phenomena which can be made serviceable to man.

Such distinctions are difficult to maintain, and a brief examination of the position will indicate that it matters little whether an investigator holds his work to be entirely connected with the operations of Nature or not. The main consideration is whether he adds to the sum of useful knowledge. Such distinctions roughly followed the two main channels of chemical research in the past, but they are obviously artificial and have no counterpart in actual experience.

A man may definitely brick up one of the windows in his study wall and determine that he will restrict

his view in a certain direction. This attitude is pedantic, and unfortunately it is not confined to any one branch of chemical activity.

If a man's work is indifferent, it will matter little whether it is called practical or academic. The crux is the value of the results obtained. This division is unfortunate, for the reason, among others, that theory, which has its origin in some practical observation, is valuable from this fact alone.

Again, the great advance, which has taken place in tinctorial chemistry, is due to the fact that theory and practice have both been involved in its development. To take another example, the Häber process has entailed an amount of research since its starting which has greatly exceeded that connected with the original discovery. This latter research has alone made the process a useful one. Only by the closest co-operation between the chemist and engineer has economic efficiency been secured. Thus an experiment, which might conceivably have adorned the lecture table, has been developed into one of the most valuable of all chemical processes.

When the respective values of static and dynamic research are more fully realised and understood, such old-fashioned divisions will be no longer used, and the different interests will become one in intent and purpose. Research in the higher branches of practical investigation has already profoundly modified theory in many directions, and in some cases have given rise to conclusions of far-reaching influence.

If investigation is graded into those parts which yield static or dynamic knowledge respectively the unnatural divisions of the past would disappear, and with this change the terms "pure" and "applied," which really mean nothing in particular, would lose their present significance and be replaced by others, which have a truer meaning.

CHAPTER III

OBSERVATION AND EXPERIMENT

"The true pilot is the man who navigates the bed of the ocean rather than its surface. The waves of the sea are an external problem."—VICTOR HUGO.

Observation and Experiment.—When it is observed that a problem calls for experimental treatment or investigation, it is necessary that a clear and complete record of all the facts connected with it shall be obtained.

For this a special training is required, which is as severe in its way as that demanded for actual experiment.

Under the best conditions, it is difficult to make certain how much of this information is gained from what we perceive, and how much from what we infer. For instance, if a man stands outside a cotton mill, he infers that it will contain all the machinery necessary for the operations connected with some stage of cotton manufacture, but he has no actual proof that such is the case.

It is unfortunately impossible to discuss this important point at any length on the present occasion, but the problem presented is one of special interest to the scientific worker, who can afford to take no risks in his information as to facts. It must be remembered that facts, which are properly recorded, depend upon the intellect, and not upon feeling; also that those which are negative must receive as much attention as those which are positive.

Relative Value of Observation.—Observations leading to new discoveries are the ones which do not agree with accepted opinion or theory as it exists for the time being. They obviously call for further experiment.

When observation alone will not give the necessary information as to the cause of an observed phenomenon, the active intervention of the investigator is necessary. It is then that he must experiment and by varying conditions determine the cause which is operative in bringing about the observed effect. If this variation of known conditions does not give the required information, he must then search for unknown ones.

In all such investigation, it is necessary that conditions or circumstances shall be varied *one at a time*. All others must be kept constant, or confusion of ideas will result, and incorrect conclusions drawn.

Upon this general procedure—so simple in itself and so difficult to approach in practice—the fabric of experimental evidence rests. It is the foundation upon which the edifice of modern research is erected.

Following the collection of all facts, which seem to directly or indirectly bear upon the proposed investigation, it is necessary to clearly define the nature of the research which is contemplated. Every condition must be set out clearly and mentally, a decision must be come to as to the line of investigation which seems to offer the best advantage.

Where investigation is concerned with research dealing with large-scale production, this rule of procedure is not always an easy one to follow. This is mainly due to the added difficulties which present themselves when some of the conditions present are still empirical.

Empiricism and Relative Knowledge.—An empirical law is one which has not yet been explained.

That is to say, the reason why it operates is unknown. The effect is observed, but the cause still remains hidden.

Such a law is regarded as a derivative, rather than an ultimate one.

An empirical law is therefore an observed uniformity, which it is presumed, can be ultimately resolved into simpler laws. It is a law which awaits explanation.

Past experience indicates that such laws are finally resolved into a comparatively small number of relative laws of causation. They exist as a result of the joint action or collocation of certain other laws. They are composite in their nature. The investigator always regards them with uncertainty, for they may only exist under the conditions originally met with.

A variation from the exact conditions or circumstances under which they were observed may either obscure, or nullify their action.

The presence of empirical law is often met with in industrial work. This follows from the fact that conditions of working are relatively complicated.

In the case of such laws, action occurs in a definite way so long as conditions are kept constant, and it is often the aim of the practical worker to determine the conditions under which such effects can be produced with reasonable certainty.

When working under such difficult conditions, as where only a part of the actions are realised or known, it sometimes follows that a workman will, by what is termed rule-of-thumb, succeed in controlling operations more successfully than the experienced investigator. By repeated observation the workman has learned the limits of successful working, and by following a path pointed out by past experience he is able to control operations to better advantage than the scientific investigator. The latter has to face

too many unknown conditions. He is misled at every step by conditions which vary through unknown causes.

The presence of so many unknown conditions will greatly try the young chemist, who has been accustomed to work with pure chemicals and to confine his work to directions, which are relatively under control. As a rule, his past experience can neither tell him much about his work, nor lead him by direct paths to a realisation of the methods he must perforce adopt, to gain an advantage under such different conditions of working.

To be successful, he must be prepared to utilise every method of investigation, which seems to offer any advantage, temporary or otherwise. A process of manufacture is, at any time, made up of a number of known and unknown conditions. Even the laws governing the known conditions may be mainly empirical. It may be acknowledged that only when empirical practice is resolved into exact method, based upon scientific knowledge, can the best results be achieved. A knowledge of the exact causes, which bring about observed changes, is a necessary preliminary to perfect conditions of working.

When it is not possible to eliminate unknown and disturbing influences, they must be met and controlled empirically, if they cannot be dealt with on strictly scientific lines. The position cannot be sterilised from objectionable and disturbing influences by a preliminary purification of raw materials. The young chemist must learn to work in their presence and by a general study of conditions, to reduce their adverse action to a minimum.

Judged from a standpoint of practice, experimental work must supplement observation and empirical methods of working wherever this is possible. There is the same difference between working in the college laboratory and the works,

that the soldier meets with when he goes from the parade ground to the battlefield.

In new industries, which have been based upon research, it might be expected that the conditions of working will be less empirical, and the system of control more scientific. This is the case in some instances, and not so in others. The so-called trade secret is nothing more than a partially observed fact, conditions being improved by taking advantage of information gained by observation. Better conditions of working have been observed, which are not understood, but merely followed. The disadvantage of such methods is that control is easily upset and no longer operative.

Such "mixed reactions" are difficult to control on account of their complexity. The temporary superiority of rule-of-thumb is real while it lasts, and the young chemist will do well to give it all the respect it deserves. Otherwise he may attempt to substitute an efficient method by another, which may be more scientific, but less useful. As a matter of experience, the operations of rule-of-thumb are very difficult to replace. Their superiority will only give way before the best endeavours of the experienced investigator. In some cases, years pass before this stage can be achieved.

Where the laboratory chemist does not possess a wide experience of manufacturing operations he is advised to go slowly, when he comes up against rule-of-thumb, especially if he does not possess the "works-sense," and the power of translating laboratory work into works practice.

There are so many points to consider, which are absent in laboratory research, that the very strangeness of his surroundings may confuse him. His ultimate position will largely depend upon not making any glaring mistake in his early years of learning. He must be prepared to walk slowly, and to make

doubly certain of every step he takes, because he lacks experience.

Nature of Empirical Knowledge.—It is incorrect to regard empirical knowledge as beneath the consideration of the scientific worker, or that it can be classified under a general term like empiricism, without further reference to its quality. The latter may be estimated on a basis of practical utility or on one calculating the skill required to secure it. It is frequently referred to by those who do not realise its importance as "guess-work," or "rule-of-thumb," but it includes knowledge obtained by experiment, when this remains unclassified, or when it cannot be referred to in terms of exact science.

That part of knowledge obtained by the experimental method, which is regarded as practical, because it is still considered as non-scientific, is strangely like the higher kinds of empirical knowledge. In fact, they are seemingly identical. It is difficult to determine whether the value of empirical knowledge is more truly arrived at on a basis of the skill exercised in obtaining it, or by its usefulness.

Four classes of empiricism can be recognised with little difficulty, and others will, no doubt, suggest themselves. The former are as follows:—

(1) Mere guess-work, which is subsequently utilised in the arts.

(2) Knowledge gained by the accidental intervention of new conditions, when this is utilised by repetition.

(3) Knowledge gained by close observation based upon extended experience.

(4) Knowledge obtained by experiment, which is of practical value but not yet scientific.

It is generally a feature of empirical knowledge that it is essentially dynamic.

Relative Significance of Observation and Experiment.—Observation is defined as a mere recording of phenomena as they occur in the ordinary course of nature.

When this course is changed by the personal intervention of the observer, he is said to experiment.

These two stages in experience have been defined by Herschell as "passive" and "active" respectively.

An experiment therefore differs from an observation in the fact that specially introduced conditions influence the result in the former case. It is in this direction that the power of the investigator is tested, both in the methods adopted and the inferences made.

The relative value of observation and experiment cannot be determined with any accuracy. It varies in different sciences. The former has not the same value in chemistry as in medicine. Its value is possibly greater in practical than in academic research. Correct observation of course plays a part in experimental investigation. The element of specialised control is the one which distinguishes experiment from observation.

The practical chemist makes great use of observation. By its aid he collects his subject-matter for experimental investigation. The more experienced a worker the greater use will he make of this aid to progress.

It represents a preliminary step in the process of investigation, which is amplified by experiment in all its stages.

Where procedure is governed by observation alone it is called empirical. Long before the experimental method was adopted, industries were firmly established. The tanning of leather, the dyeing of fabrics with natural dyes and pigments, the smelting of metals, were all practised with great success.

With all our experimenting how much is really known of the first two processes to-day? The reactions involved still defy the investigator's skill, and the actual operations are even now largely empirical.

Empiricism.—The practical investigator, therefore, guards against adverse criticism in the presence of such conditions. He extracts every ounce of practical advantage from available knowledge, preferring that which is relative rather than empirical, but accepting the latter in all cases where it is more satisfactory. The greater value of knowledge obtained by the experimental method is allowed, but it is recognised that the time has not arrived when empirical methods can be dispensed with, without a direct loss in efficiency.

It may again be pointed out to those who object on principle to empirical knowledge, that a large proportion of the data obtained by experiment is still unclassified; quantitative, but still to be brought into line with theory, and therefore still unscientific.

How far these unclassified facts differ from those of empiricism it is difficult to say. It might be argued that the one is to enquiry what the other is to economic production.

Intermediate Stage of Knowledge and Experience.—There is an intermediate stage in the full development of scientific knowledge where action is alone possible, when partially known and unclassified data are utilised.

In Faraday's words, "Ideas which may have a provisional basis of experiment are often the shades of a speculation—impressions on the mind which are allowable for the time as guides to thought and research," although "their apparent fitness and beauty vanish before the progress of real natural truth."

The practical investigator applies thought and

knowledge until success is achieved. In his progress along lines of least resistance he rejects the image of past definitions as to what knowledge should be, and utilises every source of information, which common sense indicates will aid him in his search.

In the days when processes are springing up on all sides, which owe their origin to the experimental method, it is only right that we should not lose sight of the real position of our present knowledge. The modern method has introduced industries and processes, which could not have been controlled or thought of had observation alone been utilised.

The experimental method has partially replaced the older one, and in time it may be that it alone will survive, but the great part played by those who achieved so much with such a slender guide as observation can never be passed over. Their memory will remain fresh until the last of the industrial processes surrenders to scientific law.

It is certain that the future belongs to the experimentalist. It is right to emphasise this in every way, but the constant and real aid given by observation to the scientific investigator must also be fully recognised. Observation rightly carried out will ever illumine the work of the investigator.

Branches of Chemical Activity.—Under modern conditions, chemical activity may be divided into three main sections :—

(1) Research, static or dynamic.
(2) Development and control of economic processes.
(3) Instruction of students, including post-graduate work.

In past years, the greatest investigators were practically forced to work in colleges. To-day this condition no longer applies. Laboratories have sprung up in all directions, and many industrial

corporations rely upon their own endeavours to keep them abreast of the times. Nor is the research conducted in these institutions always of a practical nature, and even when this is so, it is as scientific in its construction as that known in the past as "pure" research. Under the classification now proposed investigation is regarded as static and dynamic, as it respectively supplies general or useful information, and knowledge obtained through experimental evidence takes an added significance.

The Personal Factor.—One of the most difficult problems is to decide how far a *trained* investigator is capable of carrying out *original* research. Under modern conditions, many enter the chemical department who would under the older *régime* have remained outside. In the early days no one who had not a decided bent in the direction of experimental science would have thought of engaging in research. To-day all this is altered, and it is sufficient that a youth shall be able to pass his entrance examinations for him to embark upon a scientific career. This matter is discussed at further length elsewhere.

Even when a student shows great promise and possesses those qualifications which are known to be advantageous in such work, it will still be found that he may be successful in one section of chemical activity and fail in others. It is generally observed that a man, who does not possess what the writer would term "the works sense," is comparatively useless in large scale production. While he may be most successful when working in test tubes and beakers, he fails when he has to face the conditions which govern economic production.

His mental equipment and balance are not of the order necessary for him to succeed in this extended experience.

It is somewhat fortunate that generally the "works sense" is either fully developed or absent. With experience, one may even form an opinion as to whether a man possesses this larger sense by merely watching how he looks at a piece of complicated chemical plant. An indifferent worker may be present in a laboratory without doing much harm, but this is not so in the works.

Many can criticise the work of others, and successfully point out where it is defective or incomplete, and yet be quite unable to engage successfully on such work themselves. They lack manipulative skill and a sense of proportion, although they possess other faculties to a marked extent, including the creative power, which gives rise to important suggestions.

Provisionally chemists may be classified as follows :—

(1) Those who can successfully impart acquired knowledge to others, and therefore act successfully as teachers.

(2) Those who, in addition, have manipulative skill, and a sense of order.

(3) Those who also possess originality of thought, and the power of applying this to scientific investigation.

(4) Those who, in addition, possess "the works sense" and can carry out large scale operations, and direct others in the same.

Men of the first class should confine their attention to teaching. Those of the second class may, with advantage, be teachers, or work in a laboratory. The third class should be engaged on research, and the fourth should utilise their powers in practical research and economic production. While no hard and fast distinctions are possible, it is easy to recognise the above special qualifications in different workers.

It is not suggested that a man in class (3) should

never teach He may make an ideal teacher, for he possesses experience as well as knowledge, but he should be regarded primarily as an investigator, who may, or may not, teach others the methods of actual practice. While members of the latter classes may take up duties in the earlier ones, the reverse cannot be so successfully accomplished.

An investigation may be brilliantly conceived, but indifferently executed. The vision may be clear, but the task imperfectly carried out. It does not follow that a man with keen imagination also possesses those qualities which bring success in chemical investigation. His mind may work too swiftly, ideas following ideas so rapidly that action is deferred, or when followed up, incomplete.

Research on Practical Lines.—When the chemist enters a works, he observes a strangely new world of running machinery, steaming vats, and processes working on a vast scale in closed vessels instead of in the easily examined laboratory ones.

He must, as rapidly as possible, take stock of his new surroundings, and realise the altered conditions under which he will work in the future.

In time he will gain confidence, this being secured when he realises that large scale operations are carried out with a surprising regularity in the works, and that this will evidently afford him a foothold and allow of further advance as a result of experiment.

He will observe that unrestricted experimental work on a large scale is impossible for financial reasons. Any change which ends in failure may entail serious loss. He will do well to remember that adverse results have a way of developing after comparatively long intervals, and that failure may result from secondary changes, which subsequently come into operation.

For instance, a new process of vulcanisation may, on the face of things, seem to introduce an improvement, yet it may be that the finished material will suffer from secondary changes on keeping.

In the laboratory an unsuccessful experiment may be poured down the sink and forgotten, but in the works a considerable stock of the final product may remain to draw attention to an ill-considered effect. The added responsibility which follows when production takes place on a larger scale is very real.

The chemist has already fought half his battle when he realises that he is good at his work. This knowledge, as it is gained by experience, acts as an incentive, when things seem all awry and progress is uncertain.

The value of failure must be realised; the conditions which give rise to it must be fully considered. The young worker must set up a mental court of enquiry, and examine the position from all directions. He must endeavour to find out whether failure was inevitable, or due to lack of attention to detail, want of care, or the absence of concentration on the work in hand. Upon a correct answer much may depend.

Success comes to a worker in practical science on his own initiative or through his own capability. He may gain considerable advantage from a training which puts before him the essential features of his science. He may gain knowledge by close personal contact with those who are engaged on research, and are masters of their craft. But the time will come when he must choose his own path and follow it steadily to the end.

He will fail in originality when he merely extends the work of others without adding anything in method or practice. A slavish following of such a programme will never bring real recognition. It represents research at its ebb.

His work will only keep its interest while it remains useful. When the flood of experience advances beyond it, it will merely make history at the best, or be forgotten at the worst—a stepping stone when it has proved useful, which the flood has swept away, or in the alternative, it is buried beneath the surface and lost to sight.

Theory and Practice.—The chemist when entering a works must remember that he starts where others have left off. When examining the results previously obtained, he may well remember that the second successful climber of Mont Blanc was the *savant* Saussure, the first was the goatherd Balmat. Also that "when ignorance becomes daring, she has sometimes a sort of compass within herself—the intuition of a truth clearer oftentimes in a simple mind than in a learned brain." When all the chances of success seem to be against the experienced investigator he may sometimes still succeed by making certain that all the precautions are on his side.

When starting an investigation an opinion will naturally be formed as to the probable nature of the difficulties to be met with. Every beginning is a struggle against resistance. To commence an investigation is to find oneself surrounded by difficulties which stand as obstacles to progress. It is with the overcoming of these that practical research is mainly concerned. The rest is technique, known to many.

Fragments of fact and past experience float before the mind, to be utilised or discarded as instinct or past experience may suggest. Method governs scientific investigation, as the compass does the mariner's progress when it leads into previously undiscovered ways.

The chemist may possibly start his investigations in the works by detecting and examining some

abnormal occurrence, which, as recognised, either leads to loss, or more favourable results. In the latter case his aim will be to extend this into general practice. The discovery of such a condition is always followed up by the experienced investigator, and every possible effort is made to trace it to its source of origin, no stone being left unturned in the search.

To follow up such occurrences is one of the surest means to progress. Such an experience is of great value to the young investigator. It is one which allows of a full play of intellect and knowledge. From a practical point of view, such an experience converts the novice into a seer.

The knowledge of theory and practice possessed by the new arrival in a works will be mainly restricted to what has been termed the first stage of discovery. Almost at once he may have to virtually discard this as a means to progress, and remembering the principles which underlie scientific investigation he will work on lines similar to these, and experiment in what are to him entirely new directions.

He will have a great deal to learn. Ideas will crowd upon him from an entirely different point of view to that he has been accustomed to, where his experience has been made comparatively easy by the presence of pure material and easy conditions of working. Investigation is set upon a different stage, yet the underlying principles remain the same.

In time he will come to regard practice as comparatively stable beside theory, and will more and more rely upon past experience as a guide. Before many years have passed he will probably observe that much of the theory of his college days has already become obsolete, and no longer tenable as a guide to progress. He will remember that somehow this is not his experience in practical research. Here his methods have changed, but the older ones are still there if

they are required. Temporarily or permanently, they have passed out of experience, but under the older conditions they still remain as useful as ever. They have a permanent value, for what it is, and are capable of re-use should the occasion demand.

The practical investigator therefore holds on to past experience as to a rock. In time theory becomes to him an assertion, practice a fact.

The main advantage which scientific investigation brings with it is the certainty which accompanies it in its successful phases. Empirical methods are apt to fail at an important juncture, so do the others, but here there is a greater chance of re-establishing normal conditions by a better understanding and a more perfect control.

Time will teach another lesson. A process which yields to a simple control and gives relatively uniform results is always the better one. Of fifty processes, which seem on general lines to offer advantages, possibly only one is utilised in the works. The others may, on paper, offer advantages in certain ways, but the experienced investigator will instinctively know that they are too complicated for works practice; that control upon control will be required and that more will be lost than gained if such methods are adopted in works practice where they are not absolutely essential.

The beginner will do well to reconsider his activities when these seemingly lead to more complicated methods of working, for the latter may be outside the safe limits of working in economic production. This fact, self-evident as it is to the practical man, is often overlooked by those, who have a more limited experience.

CHAPTER IV

PRELIMINARY SURVEY AND SELECTION OF SUBJECT-MATTER

"*Zeal without knowledge is like expedition to a man in the dark.*"—NEWTON.

Survey of Past Knowledge.—The selection of a definite line for investigation will depend upon many factors. In early days, the work of others will often indicate where further knowledge is desirable, and gradually a man's personal outlook, mental qualifications and instinct will select some suitable direction for further research. A natural inclination to work in a special direction should always be allowed full play.

In many cases the nature of investigation will be determined by surrounding circumstances over which little control can be effected. Thus a chemist in a rubber works will naturally confine his main attention to investigation connected with this industry.

In any event success will come to the ordinary investigator as he becomes acquainted with the procedure of research and as he possesses a knowledge of the main principles which govern its practice.

When investigation comes through personal thought, every care should be taken to fulfil the condition that the results expected will be of immediate utility.

If the chemist has decided that his mental qualifications and training indicate that he will do better in academic than practical research, his selection will probably be connected with the study of a known

reaction working under new conditions, the confirmation of some law, which seems to be empirical, and the search for a new one if this is found to be the case.

A mere hunt for new compounds on a plan equivalent to an addition, or subtraction, sum is of little value. This simple stage of research, coupled with the recognition of the new substances produced, represents investigation in its lowest form. Of a hundred such new substances not one may have more than passing interest. As a training in manipulation and skill in selection, research of this kind may have some value, but it is far better that a selection be made where a definite advantage may be gained in the successful completion of the research. Every attempt should be made to escape from a position where no apparent advantage will be gained, other than a knowledge of how such operations are carried out. This knowledge should be secured by other means.

The powers of imagination, foresight, and successful attack will be best developed when there is a definite end in view.

In early days, research should not be attempted, which is obviously beyond the powers of the investigator, otherwise his efforts will be strained, and his attention may wander from the main issue. One should have knowledge of one's powers before navigating the rapids of a dangerous river.

Above everything, the research should promise a practical advantage. The latter condition alone will prevent a man's work leading him into a rut. The results of imitative research will be of little value to any one, and least of all to the investigator.

Simplicity a Main Factor to Success.—In academic work, as in practical investigation, results will be of value in proportion to their usefulness and apparent

simplicity. The value of original investigation is far-reaching, while research which merely follows on some one else's footsteps, may only call for observation and an extension of routine practice.

The methods employed by great investigators, apart from the precautions taken, are always simple. Far-reaching conclusions are mainly arrived at when the experienced investigator uses his natural abilities to their full extent. Thus Greiss laid the foundation for immense developments in organic chemistry when he discovered the diazo reaction. Its general applicability depends greatly upon its simplicity.

When the field of modern investigation is carefully reviewed there should be no difficulty in selecting a line of research which is practical, non-imitative, and which does not call for any great elaboration of apparatus or of materials only to be obtained with difficulty.

The worker, who starts investigation on industrial lines, will have to exert special care that he does not select for investigation a problem, which is complicated by the presence of conditions playing at cross purposes with the line of his advance. He may have to trace out a very narrow course in a wide and uncharted sea, if success is to come his way, and this experience will be found to present many difficulties over those met with in ordinary research. It is a mistake to imagine that practical investigation is more easily carried out than academic research. The contrary is often the case.

In academic research the principle that all disturbing influences shall be eliminated is always followed, and the materials used are pure. In industrial research these simple conditions are rarely present, and experience has to be gained in working under conditions, which would be considered hopeless in the college laboratory. This explains why many academic workers fail when they engage

upon industrial problems, where unknown conditions have to be faced. Conclusions have to be arrived at when nothing but past experience can act as a guide. In the past this duality of interests has kept the majority of academic workers experimenting along lines of little interest, whereas they might have devoted their attention to investigation, which would have played a double part, and secured for their endeavours results of immediate value.

While the practical investigator welcomes difficulties which add zest to his search, another class, with a different mentality, will falter in the presence of unknown conditions, and will return to the straight road and a clear run for their activities.

While it is certain that the same conditions must apply to academic and practical investigation, yet there are added responsibilities and increased difficulties to be met with in the latter, owing to the fact that the course of progress is rendered less clear by interfering circumstances.

In any case a man must be in love with his work. He must be so absorbed in it that temporary failure but adds zest to his search. Though the fabric of past knowledge and theory seem to fall about his ears, he must still work steadily on regardless of extraneous conditions, and only intent upon the ultimate success of his endeavours. If he feels this, he will succeed in practical investigation, if not, he will probably fail, and he had better return to work which eliminates such difficulties, and where research runs a more even, but possibly uneventful course.

Confidence in one's powers and the presence of a quest will often end in the overcoming of extraordinary difficulties. The man who deliberately sets out to win generally succeeds. The one who stops to consider the work of others at every stage, and looks to their results instead of his own endeavours to carry him to success, will at best produce imitative work.

He will look for chance discoveries when he should be steadily working on original lines.

The one type of worker faces nature unaided, except that he has regard for certain conditions, which can alone bring success. The other type seems to always require crutches to walk with, and consequently the higher passes are closed against him before he starts. The worker, who has a constant succession of fresh ideas and the power to choose from these and give to them a corporate existence in fact, succeeds. The task must follow the vision and investigation be completed. Resolute determination and stubbornness of purpose succeed in the long run, and the usefulness of the results obtained will follow when the difficulties, met with on the way, are utilised and brought into line with the general advance. They in their turn are compelled to give their aid, to be incorporated in the research, and become part of it.

Absence of a Common Expression in Research.—With the rapid advance, which has taken place in physical science of late years, a corresponding difficulty has arisen. The study of subjects like the physical conditions associated with chemical reactions, the advance in molecular physics, the recognition of the importance of residual affinity, and the extraordinary differences introduced by varying stages of aggregation (colloidal state, etc.), have greatly complicated our knowledge of the influence of physical properties of matter in its relation to chemical action.

This difficulty has not been lessened by the different outlook of the numerous workers who now follow up such investigations. The training of the physicist has given him a different idea and way of looking at things to that of the chemist proper.

The reconciling of these varying differences is not yet complete any more than the conflicting aims of chemistry and engineering have been settled in the works. In the one case, the so-called physical chemist fills the breach for the time being, in the other, the chemical engineer. It is interesting to note that both these stop-gaps have originated with the chemist.

Sooner or later these respective workers will realise the aims and objects of those working on the same problems from different directions, but until the mass of undigested data, which is pouring out from the different centres of research, is co-ordinated the present somewhat uncertain position must continue.

It is possible that some new discovery may make all clear, and reduce to order a position which is somewhat chaotic. The constantly changing views on theory, and the scrappy nature of much of our modern research, renders it absolutely necessary that some such examination of varying views shall be achieved.

At present the vision is clouded, and many of the so-called facts are surrounded by entanglements, unshattered by the high explosives of the old-time chemist.

The chemist fails to reconcile the physicist's many formulæ and mathematical expressions with the clear results he has laboriously obtained by direct experiment. The picture seems out of focus. But some day, no doubt, a turn of the screw will make all clear. With a common mode of expression, the inevitable understanding will follow.

The chemist still desires to set his pictures on the older stage, while the physicist, cinema-like, reels off a series of apparently disconnected pictures, with bewildering effect.

Just as the dividing line between engineering and

chemistry is imperfectly served by the engineer-chemist, so the present line of demarcation between the work of the chemist and physicist is incompletely bridged by the so-called physical chemist. The ever-accumulating mass of crude knowledge accentuates this disquieting position, but eventually some great master will take things in hand, separating the grain from the chaff, and allocating to their correct positions the remaining values and facts.

Residual Phenomena.—The importance of what are termed residual phenomena should be fully recognised by the young worker. Crookes pointed out their supreme importance and that they "may lead a man of disciplined mind and finished manipulative skill to the discovery of new elements, or new laws, or even new forces." It is interesting to note that he also considered that "upon undrilled men these possibilities are simply thrown away. They are of the highest moment to the student."

Investigators who undertake work of this nature are always careful to distinguish phenomena, which only seem to point to apparent laws. Where these are present they make certain that general conclusions are not drawn from them.

At the same time a real exception may overturn the strongest generalisation; but interfering circumstances must be specially searched for, when observations of this nature are under review.

The work of leading investigators should be watched carefully, as they deal with problems of this nature.

When the young chemist realises that discovery is the result of a definite search, where negative evidence is as important as positive fact, the realisation must come that the value of the simplest piece of research, correctly carried out, is fundamental. It is self-evident that work of this nature may be

regarded as of special value as a training for the student.

The investigator, as time goes on, will be particularly impressed by the progressive nature of his work. He will realise the value of some simple fact besides a mass of empirical data, even if the latter be expressed by a complicated mathematical expression; a sure sign, if past evidence counts for anything, that he is faced by a distorted or one-sided view of what may be in reality a simple expression.

Preliminary Search for Past Records.—This is an important part of any research. It should be undertaken in detail before actual investigation is commenced.

The student must be quite certain that he has definite knowledge of any work, which may bear directly or indirectly upon the investigation he proposes to undertake. In practical research the survey must also be extended to cover past experience.

The source of published information may be divided into four main sections:—

(1) Text-books, Dictionaries, and Monographs.
(2) Journals of Chemical and other Societies.
(3) Technical and Semi-Technical Journals.
(4) Patent Literature.

Text-books are more useful for general work and in the preliminary stage of research. There is a growing tendency for these to be devoted to special work, and where this is the case they become of corresponding importance to the investigator. Abstracted information should always be supplemented by a reference to the original communication. The details to be found there are often of first importance. They naturally cannot be looked for in text-books, where the compilers have not, as a rule, the same object before them as the investigator.

Such works as Beilstein, or Dammer in his "Anorganisch Chemie und Chem. Technologie," or Moissan's "Chimie Minerale" may be studied with advantage. The growing tendency to give reference to the original papers is a satisfactory feature of modern text-books.

Reference to Journals.—It is necessary to give special attention to any journals dealing with the subject in hand. Many of these have come into being in recent years and are confined to certain branches or sub-sections of scientific enquiry.

Thus it would be necessary for an investigator dealing with a research on Colloids to refer to the "Zeitschrift für Chemie und Industrie der Kolloide," and when dealing with Tannins and their action, to *Collegium*, the "official" journal connected with that branch of industrial research. In the case of dyeing, the *Revue Générale des Matières Colorantes*, the *Farber Zeitung*, and the *Journal of the Society of Dyers and Colourists* might be consulted.

The International Catalogue of Science and the Indexes of the Royal Society's Proceedings should be carefully examined, although the latter hardly touches on the technical side of chemistry. Reference to a certain paper or communication will often, by cross references, open out a wide field of further information. The student must in this way make a special search for previous work. The leading journals to be consulted may perhaps be taken as those abstracted for the *Journal of the Chemical Society* and for the *Society of Chemical Industry* respectively.

Résumés such as the monographs in Ahren's "Sammlung" are of special significance.

The preliminary search may also include the annual reports issued by the Chemical Society in which will be found articles covering progress in

General and Physical Chemistry, Inorganic Chemistry, Physiological Chemistry, Agricultural Chemistry, Organic Chemistry, Stereochemistry, Analytical Chemistry, Vegetable Physiology, Mineralogical Chemistry, and Radioactivity. The publications of the foreign chemical societies must also be searched.

Besides papers appearing in the journals, abstracts should be carefully considered. This search is facilitated when the collected index system is adopted. The system of abstracting adopted by the leading journals is now so complete that it may be used in the preliminary stage of an investigation with increased confidence. According to the latest information no fewer than one hundred and fifty journals have been abstracted by the Society of Chemical Industry for their journal.

Patent Literature.—In some cases an important source of information will be found in the patent literature of this country, Germany, France and U.S.A. respectively. These may be seen at the Patent Office Library in Southampton Buildings, Chancery Lane, E.C., which is open daily. Many of the technical journals, such as that of the Society of Chemical Industry, abstract patents in increasing numbers.

No likely source of information concerning past investigation should be overlooked. This search may be regarded as part of the research, and the beginner must pay special attention to it, as it is of first importance. It will reduce the possibility of an investigation being merely a repetition of previously published work. The present advanced state of chemical investigation increases the value and need of this preliminary work.

When once the nature or direction of the research is settled, any references obtained to similar work

should be carefully indexed, and a short abstract prepared dealing with their influence on the work in hand.

The search, which follows the selection of subject-matter, may be regarded as the first step in the normal path of an investigation. The importance of method must be fully realised at this stage, and should never be lost sight of until the research is completed and recorded in full detail.

Early Research.—The beginner will naturally start work on a modest scale. The results to be looked for are personal experience, training in actual manipulation, and an insight into the work of others observed in actual practice. Attention to such detail will establish method. The simplest piece of original investigation successfully carried out will bring with it confidence, and give increasing value to such work.

Faraday was extremely critical of his own efforts. In reviewing his work up to the year 1832, he divided it into three classes, good, moderate, and bad. He regarded this examination as of great benefit to himself "because of the utility they (results) have been to me, and none more than the bad, in pointing out the faults it became me to avoid." The chemist cannot do better than follow this example and at stated intervals review his past work and form an opinion of its value, and observe where it can be improved. This mental stock-taking and critical survey will prevent a man becoming too self-centred and satisfied with his work—a fatal bar to further progress.

Nor need he be discouraged if this is seemingly slow. Faraday considered that "it required twenty years to make a man in physical science, the previous period being one of infancy." It is possible that under modern conditions, this period may be reduced by one half. The "fifteen golden years"

between twenty-five and forty should carry a man far if he has the natural power and instinct, which, with energy and perseverance, brings experience, the greatest of acquired gifts.

When investigation is based upon sound lines, its importance develops in a natural way, and its usefulness grows. Under proper conditions the simplest investigation may lead to important results. This gradual increase of power may convert a worker into a great experimentalist. It has been well said "that the value of experience is not in seeing much but in seeing wisely."

Personal Qualifications.—These necessarily vary greatly in their nature. It is not easy to define their nature in words. The powers which make a Chopin are not those which make a Kelvin. It is certain that the scientific worker must possess curiosity, patience, critical comparison, and the power of seeing behind external fact and realising the true importance of things. Imagination plays a great part, it may make or mar progress, just as it is practical or the reverse. Properly controlled and directed into useful channels, it builds new worlds.

How far the qualifications necessary to successful investigation can be created by training, when the right instinct is present, is a matter for argument; but it is evident that actual experience has led Faraday, and many other great thinkers and experimentalists, to believe that when present they must be fully developed by training.

It is generally allowed that the power of observation can be largely developed by practice, and directed into new lines by convincing argument. Experience can also be continually increased by further contact with operations which come within its sphere of activity.

It has been said that "every fact and every

discovery casts a light beyond itself, and the extent to which this light is perceived depends upon the man." In addition to the powers of imagination and keen observation, a certain shrewdness or foresight is always observed in the successful worker. When he confines his attention to the main thoroughfares of progress he engages upon work of determining influence. When his activities branch out into new directions, he seems to make a subject his own. He leaves research of minor importance to others.

Such original workers make no reservations of knowledge, yet their unrivalled technique and past experience may practically give them a monopoly in such work. Such a worker "possesses the secret of novel and unsuspected solutions; what were fixed and unsurmountable barriers to trained investigators yield to his gift of magic enquiry" (H. G. Wells). It is impossible to place barriers round a born investigator or pre-determine the direction of his superiority, yet it is certain that even his work can be rendered more efficient when he possesses a thorough knowledge of the principles which have guided others when they have faced similar conditions.

Half the mistakes a man makes in the early years of his work can be prevented if he possesses a knowledge of the essential principles to success. While a born worker instinctively knows when he has departed from the true path of progress, yet the average one will often proceed, unconscious of such errors unless these are reviewed in the light of the experience of others.

Manipulative Skill.—Only extended practice can develop skill to its full measure of usefulness. It is evident that much can be achieved in this direction during the period of college training. Manipulative

skill is always of more value than an elaboration of apparatus.

Cavendish, in a simple way, obtained results indicating the proportion of oxygen in the air. These were practically identical with those subsequently obtained by Bunsen and Regnault, who worked with a greatly developed elaboration of apparatus. Yet there were natural limits to both these methods of working, and neither led to the isolation of the rarer constituents now known to be present in the air, although Cavendish's work undoubtedly pointed to their existence.

The extreme care exercised in detail by a great investigator is also illustrated in the work of Cavendish. He never conducted the simplest operations on any but a quantitative basis. He never prepared hydrogen without recording the amount of iron or zinc taken, and the volume of gas generated. He seems to have had the fine sense for detail which was so evident in the work of Faraday. The latter always repeated the experiments of others. "I am never able to make a fact my own," said he, "without seeing it." He also stated that "he could trust a fact, but always cross-examined an assertion." Sure of every step, trusting to no one's conclusions, but bringing every fact within their own experience, these great English investigators made their name known to the scientific world and placed their country's fame in the forefront of those who followed in Boyle's footsteps, accepting his views and honouring his conclusions.

A Mental Survey of Action.—Many investigators find it advantageous to visualise the different stages of their investigations. They are curious enough to form a mental picture of the reactions they are employing. This plan is undoubtedly a useful one. It often precedes the discovery of theoretical con-

clusions and generalisations as these are founded upon experimental enquiry.

While this power of picture-making may obviously be misused, yet it has been a direct aid to progress. While it must never be allowed to become the beginning and end of things, it will always remain part of the imaginative instinct, as this leads to progress in the absence of fact. It indicates the limitations of our power of direct thought and action. Its presence is a sign that knowledge is passing from fact to imagination.

As in learning a language, it is necessary to think in the same before any progress can be achieved, so in research, a similar condition is called for. These symbols of thought, crude as they may be, have proved their value by their utility.

The non-successful issue to an investigation may only indicate that the limits of fact and ordinary experience have been arrived at. If a further advance can be secured by the imagination, which for the time being enables a man to travel further along the road of progress, such an aid should not be rejected.

Just as in ordinary investigation it has been claimed that it is impossible to separate the observer from the theorist, a questioning temper and the busy suggestive mind being required at every stage, so this additional aid to experience must be received and welcomed. When it is practised by those who have past experience, and possess a regulated mind, results have been secured which have withstood the experience of fresh discovery.

Introduction of Instruments of Precision.—Since Lavoisier made use of the balance in 1778 thereby exploding the phlogiston theory, the working out of some new instrument of precision has always been welcomed and critically examined.

The invention of a new apparatus may precede or follow the discovery of a new fact. That is to say, it may either lead up to the latter or be the result of it.

The invention of the spectroscope or the ultra-microscope have practically founded new sciences and extended our knowledge to the heavenly bodies on the one hand or to molecular formation on the other. Thus such a discovery may be regarded as the equivalent of an extension of our senses.

To-day, the number of these aids to progress is large, and investigation is often facilitated, or even made possible, by them. The investigator therefore makes full use of these and takes every care that he is acquainted with them, and the limits within which their usefulness can be employed.

Cost of Experimenting.—The compilation by the Royal Society of the more important scientific investigations up to the year 1879 amounted to £10,000. It was considered that the cost of these researches must have run into several millions, and that there were made entirely at the expense of the investigators themselves "nearly all of whom were men of limited means."

Of the sum expended on modern research by industrial corporations little need be said. The experiments on the production of synthetic indigo have been stated to run to a million sterling before a pound of the material was marketed.

The results obtained by the experimental methods in the practical sciences have still further increased the interest which is taken in science. In the arts of peace and war the combined efforts of the chemist, physicist and engineer determine progress.

Many of the larger industrial laboratories are equipped in a very elaborate manner. A certain chemical combination in Germany employed not less

than a thousand chemists just prior to the war. This policy was dictated by purely industrial aims, past experience having proved the extreme importance of research when organised on efficient lines.

The carrying out of this work offers unexampled opportunities to the chemist who is qualified both by training and natural ability. He must have his mind stored with the chief facts and principles of science and he "must be able to imagine, invent, manipulate, observe, compare, and reason." In the ever-widening field of practical science the chemist must always occupy a prominent position. From a national point of view his responsibility is immense. Each day it is more evident that the nation, which pays attention to the training of its chemists and determines that they shall receive unstinted recognition, will be the one who will go furthest in the direction of security and the building up of an industrial system which will offer the best working conditions for labour, and the greatest efficiency in the use of raw material.

CHAPTER V

METHODS OF INVESTIGATION

"*No scientific discovery can with any justice be considered as due to accident.*"—GORE.

General Procedure.—It is seldom that the original course of a research is followed in every particular. During the whole experimental period, the investigator is constantly on the look out for better ways of reaching the desired goal, and in many instances alternate methods have to be examined in order that it may be known whether they give better results than the original one. In a process of reduction possibly only one of the available reagents may give the desired result. In other directions this same phenomenon will be observed.

It therefore happens that a research seldom finishes up on the exact lines proposed. In extreme cases the original scheme of working may have to be entirely replaced by another, and different methods adopted in order that the desired result may be obtained.

Such changes test the skill of the chemist to the uttermost, and the overcoming of them becomes the chief matter of the research.

When research is carried out under industrial conditions many additional difficulties are met with, and in some cases these are so numerous that the research has to be abandoned for the time being. At this stage the experienced worker will sometimes carry on the investigation on more or less empirical lines, and thus industrial operations will be carried

out under a control, which is partly scientific and partly empirical.

While such conditions could not be countenanced in academic research, they give satisfactory results in practice. They represent a first step towards a scientific control, with the alternative that large scale operations must be left entirely in the hands of non-scientific workers.

As a temporary guide to progress such methods are often of great value, especially when they are utilised by those who have a sound knowledge of the ways of industrial processes.

It must be fully realised that in the majority of cases the only way of securing a scientific control is to advance by slow stages. In some cases the position seems to be so hopeless when it is compared with available knowledge that all that is possible is the setting up of improved methods of empirical control.

The work of the chemist during the intermediate stage of semi-scientific control is always difficult. Before a scientific control is possible, everything must be known about a process. The discovery of the remaining difficulties will generally lead to a further application of scientific knowledge and by such means, and generally in slow stages, the ultimate goal will be reached.

Working Conditions.—There is no advantage in a student rushing into an elaborate research. He may gain what he requires by easier methods, where comparatively simple manipulation is called for.

Research may be roughly divided into two classes. In the first, investigation is concerned with known or general reactions, extended to cover new substances, or where information is obtained mainly through the aid of some already available instrument of precision, which enables further data to be gained by its use.

In the second division, original investigation is called for, and the mental powers which are associated with such discoveries. New reactions and methods of working are discovered, and possibly means have to be devised in order that the results arising out of the research can be recognised and recorded.

The investigations of the second order attract from their novelty, and the investigator himself gains great advantage by securing a first-hand knowledge of previously unrecognised fact, and finding himself in the position of being able to suggest a possible explanation of the same.

The first class of investigation is obviously more suited to the requirements of the student, and there is a greater advantage in carrying this out unaided than in engaging in a complicated research where the ideas and progress are entirely controlled by one with more experience. The mental training is less satisfactory in the latter case, although the experience gained in manipulation is possibly greater.

There is no reason why he should not go to a more experienced worker, and discuss the different points with him as they arise, or that he should not accept hints where his own knowledge fails to supply him with points of detail, which must be settled before he can continue his work with advantage.

If the results obtained are not worthy of publication, he will have taken the first step and gained personal knowledge of research conditions. He will have the experience of bringing to light for the first time fresh fact. He will also learn that a mere mechanical following out of certain reactions must be supplemented by a process of thought, possibly combined with any past experience he can gather from those who have greater experience. The experience he gains in the plains will, in time, enable him to climb the hills.

When research is started in the college it is natural that it should be of a nature, which can be successfully negotiated on a laboratory scale.

The development of our knowledge of organic chemistry owes much to the fact that it can be successfully carried to an issue on a laboratory scale. From this, and the fact that the selection of subject-matter is less difficult, this branch of chemistry has received great attention.

Inorganic research has been correspondingly neglected, except on the physical side, although there still remain problems of great importance. But these are not so easily recognised, nor can main reactions in this branch of chemistry be followed up almost to infinity as in organic work. The clue that further work is needed in organic chemistry is often only recognised in the works.

Vast though it is, the field of "organic" research has been so exploited, that it no longer offers the same advantage to the investigator in the college. Important conclusions are only arrived at with increasing difficulty. The fashion is therefore running in new directions, and bio-chemistry, electro-chemistry, catalysis, physical chemistry, colloidal chemistry, all compete for recognition, and gain it in increasing volume.

The Time Factor in Experimental Science.—Chemistry is favoured, as a rule, by the fact that the time of reaction is relatively short. In geology, the other extreme is reached, and observation cannot be verified by experiment.

Even in some cases, like that of the formation of coal, the chemist can apparently hasten the natural process by artificial means. Great pressure at temperatures in the neighbourhood of 100° C. has given changes in wood, which seem equivalent to the slower processes of nature.

In practical research industrial operations often have to be observed over long periods before the exact conditions sought for can be recognised. A patience almost equal to that of a Darwin is sometimes necessary.

In cases where a change is very slow in taking place, useful knowledge may be obtained by observing what happens over a comparatively shorter period, and from this forming an opinion of the greater effect which may be anticipated.

Methods of Research.—When once the direction of an investigation has been settled, and a *résumé* of all previous knowledge on the subject prepared, there is nothing left but to get on with the research itself. In ways the nature of expected results will already have been thought out.

When the ordinary apparatus of the laboratory is sufficient no advantage will be gained by using more elaborate means. In advanced research specially devised apparatus is often necessary. For example, it is impossible to carry out an investigation, which requires high temperature conditions, without an electric furnace, fitted with all the necessary instruments for recording actual temperatures, etc. Without the electrical furnace Moissan could never have carried out his classic work on high temperature reactions. Without the vacuum-lined vessel many experiments in low temperature reactions would have been equally impossible. A piece of apparatus or an instrument of precision may be an essential factor in investigations of this order.

Research will therefore involve the use of :—

(1) The ordinary apparatus of the laboratory.
(2) Special, but already described apparatus.
(3) Apparatus which has to be specially devised or invented.

Great practical skill and power of manipulation must be present in the last case, and the invention of the apparatus itself may be the chief part of the research, the subsequent recording of results being of secondary importance. Should the chance present itself such an investigation should be closely followed by the young chemist. He will then follow in detail the stages of development as they occur when an experienced investigator is at work.

A study of the apparatus used by the great workers in the past will impress the student with the advisability of keeping this as simple as circumstances will admit. By such means the experimental error is reduced to smaller proportions and conditions of working are likely to remain more constant, both of these being vital to success.

The young chemist, who is determined to succeed, and feels that he is qualified to undertake original investigation, should start this work while theory is still well in hand. If this is not possible, the student should leave with a determination ultimately to engage in such work. In the latter case, much valuable time may be lost in obtaining the necessary experience in after life. The importance of obtaining a working knowledge of the principles, which underlie scientific investigation during the college period, cannot be too clearly emphasised.

Aids to Research.—Familiarity with these conditions is essential at an early stage. This is a certain aid to future success. Beside the fact that this knowledge is at the base of all works experience, a state of mind is engendered, which persists.

Another factor, which operates strongly in the same direction, is observed in many cases. In certain institutions an enthusiasm has been engendered by teachers inspiring their students with similar ideals to those held by themselves. By imparting their

special methods of investigation to the students and thus giving a direction to their future work, certain "schools" have been formed. These have carried investigation to further limits than could otherwise be expected.

Another influence, not so generally understood, is frequently present, and is hardly less far-reaching in its effects, although it is of an impersonal nature.

It is felt by those who are constantly in contact with operations proceeding on a large scale. Its influence is difficult to define, but those under it are known as possessing a practical turn of mind. They have the "works sense" highly developed, and secure practical results.

By intuition, they possess a power of initiation, which is seldom met with in others.

This experience confers the quality of caution and foresight and leads its possessors to work in practical and useful directions. Such qualifications frequently enable a man to outclass another, who has a more widely set knowledge of general fact and theoretical attainment.

There is no real significance in reactions conducted on a 10-gramme basis, which is not equally present when operations proceed on a scale measured in tons. Nor is there any special magic, beyond that of convenience, in the glass beaker or the platinum boat, which is not equally present in the salt pan or the blast furnace. Rather is there an added responsibility when operations are conducted on this extensive scale.

The chemist must aim at a wide experience and knowledge of a general order. He must prepare himself to be equally at home in all branches of chemical research. Such a mental outfit can alone make him a successful investigator in the works. He must take a wide view of his subject and be

prepared to follow up his investigations in whatever direction they may lead.

This is a task of considerable magnitude, but it must be faced by all desiring to make their mark in that branch of science concerned with production on an economic scale.

CHAPTER VI

PHILOSOPHY AND EXPERIMENTAL SCIENCE

"His work he knew, but the agitation which surrounded him far and wide at all times perplexed him with its eternal questionings."—VICTOR HUGO.

Value of Theory.—In the practical sciences theory is of little account unless it is based upon, or supported by, experimental fact. When this condition is complied with the influence of theory on practice is legitimate, and in many cases its use leads to a direct advance in progress.

The value of theory founded entirely upon the imagination is always uncertain. It must be ever received with caution, and only used in a temporary way when all other aids fail. However convincing it may seem to the intellect, it must never be received in preference to fact.

In past years, there was a tendency to regard research, which is not concerned with some point in theory, as standing on a lower plane. This view is no longer accepted, results being compared for their usefulness rather than their ingenuity. It would be better, for instance, to secure by research the conditions necessary for the production of synthetic rubber, than to be able to write a dissertation proving that this operation was not an impossible one. The former would be useful, the latter would lead to nowhere in particular.

Little real loss follows the acceptance of the statement that theory must either fall into line with

practice or be discarded for some other theory that does. This limits false claims, and gives theory its true meaning and an outstanding value. When theory overloads practice its usefulness diminishes. The normal state is reached when practice advances with the full support of theory.

Philosophy and Science.—The relationship between philosophy and the practical sciences has been revised of recent years. Before the connection between these branches of mental activity can be understood, it is necessary that their aims and objects shall be correctly defined.

An attempt has been made to raise the former on to a higher plane than experimental science, philosophy claiming the right critically to examine the hypothesis and conclusions of the investigator. Herbert Spencer considered that the truths of philosophy bear the same relation to the higher scientific truths that these in their turn bear to the lower scientific ones. By this further process he held that the generalisations of the philosopher comprehend and consolidate the widest generalisations of science. The student, who is interested in this subject, may consult Sidgwick's "Philosophy."

Of metaphysics the ordinary individual takes a lesser interest, accepting the statement that it ends in "reducing self-deception to a fine art." The practical investigator has little time to waste over such matters, and he will do well to ignore theoretical speculations; which are so far removed from a basis of fact. The statement by James that before such speculations the "intellect comes to rest in a state of admiring contemplation" sufficiently sums up the opinion of most practical workers on the theories put forward by metaphysicians.

Rather will the student turn to Faraday, who, in his practical way, defined the philosopher in terms

which lead one into fresh air. "The philosopher," said he, "should be a man willing to listen to every suggestion, but determined to judge for himself. To be of no school, and in doctrine have no master. He should not be a respecter of persons, but of things. Truth should be his primary object. If to these qualities be added industry, he may, indeed, hope to walk within the veil of the temple of nature." When a scientific worker's aims fall in with these he will come to appreciate the work of others, who are travelling along the same road. He will welcome advance from whatever quarter it may come, and will gradually gain a position where he can carry on his labours without finding it necessary to belittle the results obtained by others. Surrounded by such natural conditions, he will work with redoubled energy and goodwill.

Value of Results.—It is incorrect for the practical worker to assume that static knowledge has no interest for him. He must have a general knowledge of fact and theory, but it is allowable that he should examine this from his own point of view. Theory is often modified in the light of this wider and more practical experience.

Outside its practical use, theory is of little importance. Its value lies in the use the practical investigator can make of it. Just so far as it is an aid to progress he welcomes it. The value of theory rests entirely in its utility. It is judged by its influence rather than its ingenuity.

The importance of disinterested investigation is beyond question. When such static knowledge becomes dynamic it is a sign that its usefulness has been demonstrated.

The ultimate value of theory as this is used at any period is not evident. The great conception of the benzene ring may have less real significance

than a daisy chain, but it has brought about an extraordinary advance in practice. Speculations as to space formulæ and the relative positions of the atoms in a molecule may be equally wide of the mark. They may belong to the period of childhood of science, but their value has been demonstrated by the advance in practice which has followed their consideration.

The ever-changing form of theory, which sometimes leads to a complete reversal of previously held ideas, keeps present fact from becoming too important when the rate of progress slows down inordinately or becomes restricted in its direction.

Chemistry and the other Practical Sciences.—Where an efficient exchange of ideas is secured between the different branches of experimental science, the results obtained in one section are often seen to greatly influence those of other branches. The progress of knowledge now covers such a wide area, that the significance of an advance in one direction may be unrealised in others.

The presence of a new fact, when it is determining in its influence over the comparatively narrow front occupied by the workers, who are immediately concerned with it, cannot fail in effect to influence the whole line of advance. By close investigation other sections of workers may arrive at decisions of almost equal importance, as these concern their own particular subjects.

Unexpected light may thus be thrown upon problems, which, from their outward guise, seem to be little related to the original facts. The rapid accumulation of fact in the experimental sciences almost compels investigators to specialise, and this leads a man gradually to overlook the fact that the results obtained by others may be of the greatest importance to him in his special work.

Approaching natural law from different directions the roads seem to be entirely disconnected. Yet a survey of the whole position must lead to the conclusion that differences are due more to a restricted view of things than to actual fact.

The molecule of the chemist is the same one that the physicist is so busy tracking down. The play of the atoms is the same in all cases, and now it would seem that the action of electrons is to become a matter of peculiar interest to the chemist, their direct effect in cases of catalysis being strongly suspected. In this, and possibly many other directions the key to previously unexplained reactions may lie. Such developments call for an ever-increasing exchange of ideas and data.

The broadest possible grasp of general scientific knowledge will always remain the chief asset of the student. Specialisation is the opportunity of the experienced investigator. A certain class of investigator already makes this cross-reference his chief weapon, striving to secure for himself the advantage, which others have gained when working in different directions.

It is obvious that the ultimate results obtained in one section of science will have to be sanctioned by the others. They will then be more generally useful owing to their greater certainty. A wider outlook leads to conclusions, which are more correct, because they have been considered from a higher standpoint. The exchange value of facts and theory will thus gradually increase, and the correlation of interests will lead to a final state of knowledge where the workers engaged will close up their ranks and advance together instead of by separate units.

The investigator will welcome the ever-growing list of reference books devoted to special subjects. In many cases, these afford a ready means of reference

to the salient points in theory and practice. This new development widens out the horizon for the worker by increasing the means by which such information may be obtained.

Future Developments.—A few examples may be considered which suggest themselves as having reference to this special development.

The first one chosen is bio-chemical. Meldola pointed out ("Chemical Synthesis of Vital Products," 1904) that even if we have in the field of carbon chemistry produced thousands of compounds which do not, and probably never will be found to exist in living organisms, there is no justification in assuming that we have reached a stage where it is unimportant whether an organic compound is producible by vital chemistry, or that the known laboratory methods are equivalents of the unknown vital ones.

A simple case will illustrate this. "The fundamental synthesis *par excellence*, in which carbon dioxide is absorbed by an organised compound and the product, or products, decomposed with the liberation of oxygen, is as yet without a laboratory parallel." In a similar way it may be claimed that although enzyme action may be imitated in the laboratory, no hydrolysing agent of the nature of an enzyme has ever been synthetised.

Until such vital points as this one are settled one way or the other it is essential that the chemist and physiologist should co-operate on the closest lines. Relative dependence must be the watchword of modern investigation in this direction in order that the future of bio-chemistry may be assured, and this science established on a satisfactory basis. The subject is a fascinating one, and one to which the student in search of matter for further investigation should pay special attention.

In a similar way the proteins offer an ever-widening field for research. Here the conditions are exceedingly complex, and an almost unexplored region has yet to be investigated. Future developments cannot fail to be of a startling nature, and of equal interest to the physiologist as the chemist.

The subject of the alkaloids offers another field which must yield results of great practical and theoretical importance. A reference to Vegetable Alkaloids by Pictet and Biddle, or to a series of volumes published in 1900, 1905, and 1908 respectively, under the title "Die Alkaloidchemie," will give the student some indication of the scope of this branch of chemistry, and its present position.

It is difficult to over-estimate the opportunity which catalysis, and the general reactions classified under this heading, offers to the investigator, especially when the recent developments in this direction are considered. In its modern phrase, it has been extended to organic chemistry. As practised at high temperatures by Sabatier and Sanderens and others, it can be utilised in many ways, in processes involving reduction, hydration, oxidation, and elimination of halogen hydride, etc. On the industrial side, practical use of this action has been made in the manufacture of nitric acid. Its use in the manufacture of sulphuric acid is common knowledge. These processes are being extended industrially in many directions and developments of an increasingly important nature must be expected.

Scope and Nature of Application.—The successful application of these methods generally turn upon attention to minute detail; systematic research is the only instrument which can advance our knowledge in this direction, especially as many of these reactions are reversible. The theory is undeveloped,

and the practical side may be regarded as almost virgin ground. The influence of third substances in minute quantity may alter the normal direction of the reaction, or may determine by their presence, or absence, the success of these processes from an industrial point of view.

In recent annual reports of the Chemical Society a general summary of results obtained in the domain of organic chemistry will be found.

"Unsaturation" offers a wide field for research. Also the relation between colour and constitution, which may throw light upon many other problems, and has helped to explain the mechanism of chemical change—a matter of the first importance.

Physical chemistry and such subjects as the solution state, molecular weight, thermodynamics, chemical dynamics of homogeneous and heterogeneous systems, chemical equilibrium, and many other similar subjects has under modern enquiry developed to an amazing experience, but such investigation demands considerable knowledge and the use of special apparatus if research is to be undertaken with any certainty.

Stereo-chemistry, dealing as it does with space—as distinct from structural—formulæ, has given rise to speculations of an advanced character. Some idea of its present scope may be gained by reference to "Stereo-chemistry," by A. W. Stewart, where the phenomena of steric hindrance, relation between space formulæ and chemical properties, substitution and stability, and other equally important questions are discussed.

The present position of organic chemistry is exceedingly complex. In "Die Synthetisch organische Chemie der Neuzeit" Schmidt deals with the advance in synthetic organic chemistry. If the student will refer to Cohn's "Algemeine Gesichtspunkte der organischen Chemie," he will find many

hints which will be invaluable in the conduct of research of this nature. Beilstein's "Handbuch der organischen Chemie" and Richter's "Lexicon der Kohenstoffverbindungen" are indispensable reference books.

Fischer's work has been reprinted in a series of publications dealing with the sugars, purines, and polypeptides respectively, and a study of his work and methods, somewhat elaborate, is particularly interesting.

Enough has perhaps been said as to the importance of research in connection with theory and the practical results which have followed such investigations. Whether by such means we shall ever arrive at the goal which has been defined by Freer as a "perfect human knowledge by which from any given premiss the logical conclusion may be drawn with unerring accuracy," it is impossible to surmise.

Modern Research.—The student may regard with a sense of awe the increase in the number of important sub-sections into which chemical research has been divided. He may trace the rise of stereo-chemistry to the recorded results connected with optical activity, and a determined and definite search for an optically active compound, owing its asymmetry to the molecule alone, and not to an asymmetric carbon atom. The relation between stereo-chemistry and physiology well illustrates the inter-relationship of the experimental sciences.

The study of enzyme action is entering into a new phase with the suggestion that radiation plays a part in the action of these obscure bodies.

Recent developments indicate a rich harvest of fact in the future. This cannot fail to create within the student's mind a deeper enthusiasm, especially when the vast area of unexplored ground is realised.

There is hardly a science, art or industry which can escape the influence of the chemist. The part played by the latter is yet unrealised. For instance, physical science is but a latter-day development of chemistry, and Professor Rutherford claimed some time ago that the physical men were the pioneers in electrical engineering.

New sciences spring up and seemingly develop on individual lines, only to be subsequently inter-related and closely woven into the general fabric of scientific activity, which, erected on a sure basis of research as set out by Robert Boyle, is determining the physical destiny of man.

CHAPTER VII

CHEMICAL RESEARCH AND INDUSTRY

"He that will not apply new remedies must expect new evils. They that reverence too much the old are but a scorn to the new."—FRANCIS BACON.

Science and Industry.—The success of chemistry as a science, and its obvious connection with large-scale manufacture, led to a close examination into its possible utility as a guide to progress. So intimate has this connection become that in many industries the control of operations has passed into the hands of chemists. It is evident, that this co-operation must increase in the future until the time when industry will become a branch of science, and its control will pass to those who possess the scientific instinct, and the power of investigation.

It would be difficult to call to mind any industry, which will not benefit when the control of manufacturing operations passes to science. In the preparation of raw materials, and in all the operations of large-scale production of manufactured material, the chemist can influence progress by increasing efficiency and obtaining better results, with a less expenditure of labour.

It does not follow that such an influence can be directly seen in the final product. In many cases this is not obvious even to the experienced.

It is hardly necessary to set out a list of all the industries, which are controlled or influenced by the chemist's work, but a reference to the headings of abstracts in the *Journal of the Society of Chemical*

Industry will give the uninitiated an idea as to the immense scope of this influence. The following headings from this source may be set down here for the sake of ready reference: General Plant, Machinery, Fuel, Gas, Mineral Oils, Waxes, Destructive Distillation, Heating, Lighting; Tar and Tar Products; Colouring Matters and Dyes; Fibres, Textiles, Cellulose, Paper; Bleaching, Dyeing, Printing, Finishing; Acids, Alkalis, Salts; Non-Metallic Elements; Glass, Ceramics; Building Materials; Metals, Metallurgy; Electro-Metallurgy; Electro-Chemistry; Fats, Oils, Waxes; Paints, Pigments, Varnishes, Resins; India-rubber, Gutta-percha; Leather, Bone, Glue; Soils, Fertilisers; Sugars, Starches, Germs, Fermentation; Foods; Water Purification, Sanitation; Organic Products; Medicinal Substances, Essential Oils; Photographic Materials and Processes; Explosives, Matches. These divisions indicate the main branches of industry which entail chemical research, and investigation, in their development.

In addition to this influence on established industries, many new ones have been called into existence, as the result of chemical research. Some of these are firmly established, and of great importance. That dealing with the fixation of atmospheric nitrogen already supplies certain countries with cheap nitric acid, ammonia, nitrates and cyanides, urea, etc., as it has supplied most of the nitric acid used during the war. The artificial silk industry has already supplied the markets with a cheap and efficient substitute for real silk. The artificial alizarin and indigo industries have reached a stage of fearless activity, and have profoundly affected the position of the corresponding natural products, having to an extent replaced them.

In all such cases the conditions of investigation and development may differ from those which are

concerned with "*constant speculation on the lines of a more rational theory*," but the general principles underlying the two branches of research are identical. The differences, which exist, are confined to detail, and are in many cases mainly due to the relative scale of working adopted.

Thus an ideal training is one which enables the chemist to work in theoretical or economic chemistry. This can only be secured when it includes a knowledge of the principles and practice, of research, as they are common to both.

Utility of Economic Research.—The advantage of a correct solution to these investigations must in some way be clearly indicated. The probable result of a successful issue can often be considered before the research is undertaken. Thus, the utility of a process for producing synthetic rubber at a cheap rate is self-evident. Such problems have therefore an economic interest. They are often considered from this standpoint by associations, individuals, or private firms.

Under modern conditions the success met with in many directions has been substantial. In the much advertised case of the aniline dye industry it has been found possible to establish laboratories in which a large staff of chemists are employed on research, from which important developments have resulted. Scientific investigation has proved to be in this, as it should in other cases, an essential factor to industrial success.

Connection between Theory and Practice.—An industrial application often follows naturally on an investigation, which, in its inception and characteristics, is only of theoretical importance. The development of the Mond nickel process from the original investigation of carbonyls is a case in point. The systematic study of the general properties of colloids,

and their reactions, is known to have exercised a profound influence on certain industries. Another example, which might be mentioned, is the influence of the metallographic study of alloys and metals on the metal industry generally: Auer von Welsbach's work on rare earths in connection with the incandescent mantle industry may also be cited.

The development of the Mond process to its present commanding position in the industrial extraction of nickel is known to have presented immense difficulties, which were at one time looked upon as almost insurmountable. Its successful manipulation on the large scale is one of the triumphs of engineering chemistry.

The connection between investigation undertaken in connection with theory, and that of industrial investigation conducted on scientific lines is too evident to require further comment. The former has occupied a definite and commanding position; owing to the fact that it has mainly been conducted in college laboratories, where the authors have had for years a monopoly of publication so far as results are concerned.

The ultimate fusion of the respective interests of theory and practice, which must follow as a direct result of a closer relationship between the two sections, will naturally lead to fresh developments. With this will come a further advance in the influence which science exercises over industry. Its influence in this direction is to-day self-evident. All that remains, is to develop its latent-power to the greatest extent.

Aims of the Practical Investigator.—The present development of the gold industry of the Transvaal has been only possible through investigations conducted on the action of cyanides on metallic gold. Equally important developments in the textile

industry have followed the study of the action of caustic soda on cellulose under varying conditions of physical strain.

In both cases, however, the working out of detail was the important factor. The solubility of gold in cyanide solution, and the action of caustic soda on cotton were both known for years before any important practical application resulted. The extreme importance of an investigation being carried out scientifically, and to its full limit, is being constantly demonstrated. It is beyond dispute that the Transvaal gold industry owes its existence to-day to the cyanide process, and that without this hardly a mine could work at a profit.

The object before the practical investigator (so far as the utilisation of the results of theory is concerned) is to reduce the period between discovery and its industrial use to a minimum. The aim of the chemist is to achieve this in the shortest possible time, and secure the full advantage of such investigation. Many cases might be quoted where the direct influence of theory has alone given a clue to the solution of important problems in industry.

The general statement that all scientific knowledge will at some time be utilised, and have an influence on industrial developments, may be regarded as correct in its widest sense, when it is remembered that evidence of a negative character is sometimes almost as valuable as positive information. In industrial research it is often as useful to know what not to do, as the reverse.

It is obviously impossible to predict how soon knowledge may be usefully applied, and therefore with a view to reducing this inevitable delay, any unnatural division between academic and industrial research should be reduced to its narrowest limit. This condition may best be met by the practical investigator having a sound working knowledge of theory.

Scale of Working.—It is sometimes very difficult to decide the scale upon which the investigation shall be conducted. This is an important point, and one which will largely depend upon the possible aims and developments looked for. It is generally found that processes worked out in the laboratory, with a view to their ultimate use on an economic scale, have to be subsequently modified in many ways. In industrial research other conditions apply to those observed when working in a laboratory, where results are obtained which are complete in themselves. In the face of this condition, the past experience and working conditions of the investigator will mainly determine the actual scale on which the research is conducted.

The industrial chemist must have knowledge of the general conditions involved, when laboratory investigation has to be extended to practice on the larger scale. Subsequent difficulties may often be obviated by working under correct conditions in the laboratory in the first place; and it is in determining these that practical experience plays an important part.

Experimental Works.—The natural difficulties met with in this transition stage may be lessened in many cases by the establishment of experimental work, operating on an intermediate scale, which can be regarded as the equivalent of full-scale conditions. In this way the ultimate cost of production, and methods of procedure, may be more accurately estimated and ascertained.

Experimental works dealing with processes connected with the fixation of atmospheric nitrogen have been set up in Norway. A similar one existed at Spandau for the purpose of establishing the value of processes, which have for their object the manufacture of the industrial scale of nitrogen products

from cyanamide. Many other cases may be brought to mind.

Where economic value cannot be accurately estimated, this procedure should be followed. Under modern conditions of manufacture, new reactions are generally dealt with on an intermediate scale, especially when the conditions are exceptional, or novel, in their nature. This course is always a safe one to follow under any circumstances, and is to be generally recommended.

It is not possible on the present occasion to consider such matters in detail; or to do more than touch upon examples in such procedure; but a few cases may be conveniently selected to give the student some indication as to their general nature.

A useful example is perhaps that of the manufacture of hydrogen for commercial purposes. Preparation by the action of zinc has no longer any special interest. During the Boer war it is said that this gas was prepared for balloon purposes from the action of concentrated caustic soda on aluminium shavings. Another process, which has possibilities, and has been made use of, is the decomposition of calcium hydride. Hydrogen gas is passed into molten calcium in its preparation. Frank has proposed the method of passing water gas over calcium carbide with subsequent removal of oxides of carbon. Another method of preparation seems to be the electric one, but the action of steam on iron filings is said to have a future before it, especially when the resulting oxide is subsequently reduced by means of water gas, etc., and the process made a continuous one.

The difficulties of working these processes on a large scale cannot always be overcome in practice, and it is in such work that modern engineering chemistry plays such an important part.

This example illustrates in a simple way the position

a problem of this character may occupy during any intermediate stage in its development, when the relative values of the different processes are difficult to determine, and where past experience is practically the only guide of any value, and also when the investigation is finally completed, but commercial data is not yet available.

Treatment of Ores.—The work done at Mansfeld, in Germany, in the direction of the treatment of copper ores may also be taken as a typical example. Augustin, working some sixty years ago, found that when finely crushed copper *mattes* were leached with sodium chloride the silver present was converted into chloride, and that this could be removed by solution in hot brine. Ziervogel subsequently found that by careful washing, coupled with a control of the temperature of the furnace, the silver could be converted into silver sulphate, which could then be washed out and recovered by precipitation on copper by the Augustin process. This process met with great success in Colorado, 2,770 tons of silver sulphate being recovered by this means at Argo alone. Another recent introduction at Mansfeld is the successful production of sulphuric acid from the converter gases produced in smelting the copper ore.

Again, in America, a few years ago, the Tennessee Copper Company were making 200,000 tons of tower acid per annum from the waste sulphur, while the Washoe Works of the Anaconda Company were still discharging enough sulphur into the air to make 1,400,000 tons of acid per annum.

Metallurgical operations are essentially chemical in their nature. Many of the most important operations have to be conducted under supervision of trained chemists. It may be taken for granted, however, that in most cases of the treatment of ores,

where any special difficulty is met with, that a very active co-operation of the chemist, miner, and metallurgist, is essential to success. Ores can then be worked, and give satisfactory profit, which would be "impossibles" in the absence of this mutual understanding and support.

The Practical Man.—In the past, many of the most promising processes connected with metallurgy were invented by "practical men," and subsequently chemists were occupied in determining their nature and control. The chemist has now, however, established a more definite position, and from the commencement assumes the direction of affairs in such investigations. Thus we see the gradual supplanting of the empirical method by that of experiment. This is inevitable in the case of a long continued development in any industry working under modern conditions.

The part played by chemistry in connection with metallurgy has been of recent years a determining one. The processes of reduction and oxidation, selective solution, and many others of equal importance, all demand a definite knowledge of chemical procedure. In fact, the processes themselves are strictly chemical ones. The results sometimes obtained are astonishing. In the case of the extraction of gold from its ores by cyanide solution, a saving of a penny per lb. in the price of cyanide means a further reduction in working expenses of £70,000 in the Johannesburg district alone.

The treatment of silver ores by this process also offers possibilities. The bi-sulphite treatment for zinc ores also suggests important developments. Many other examples will occur to the student. Among these, the results obtained from the study of the properties of metals and alloys suggest that, in certain directions, improvements, which can

hardly be guessed at, will be made in industrial practice as a result of extended work in this direction.

The financial gain offered for successful investigation is considerable. The commercial treatment of arsenic-cobalt-nickel ores, for instance, holds out great possibilities.

In electro-chemistry the advance has been phenomenal, and entirely new industries are being evolved. The original manufacture of calcium carbide has in its turn led to the production of cyanamides, which apart from their direct value as fertilisers have, in their turn, given rise to the manufacture of ammonia, nitric acid and cyanides on an industrial scale. Developments in other directions have led to the direct fixation of nitric acid from the atmosphere. The production of calcium and sodium in large quantities, and many other substances also, has resulted from a study of the conditions of the electrical furnace which afford a means of inducing chemical action. This, in its extension, has led to the reduction, on a commercial scale, of metals like iron.

Catalysis.—The definite study of the action of catalysis has led to results which are destined to revolutionise many industries. Examples of this are already seen in the Deacon process of manufacturing nitric acid, and the Raschig method of making sulphuric acid and the hardening of fats and oils. The field opened here is a wide one, and covers inorganic reactions as well as organic ones. The oxidation of naphthalene into phthalic acid, which has played so large a part in the manufacture of artificial indigo, is a case in point. Ostwald has pointed out (as quoted by Kennedy Duncan) that "if one considers that the acceleration of reactions by catalytic means, occurs without the expenditure

of energy, and that in all technical work, including chemical, time is money, it is evident that the systematic use of catalysis may lead to far-reaching changes in technology." It is quite impossible to suggest that any bounds can be set to future development in this direction, any more than in the case of electro-chemistry, or many other new branches of chemical industry which might be mentioned.

These few examples must serve to indicate the part which chemical investigation is playing in modern industry. It is remodelling procedure in industries of old standing; and, what is more important, supplying the necessary information for the establishment of a series of new ones which owe their existence to experimental investigation. In many cases these introduce new products, and processes, of great novelty and utility.

CHAPTER VIII

RESEARCH IN RELATION TO ANALYSIS

"Every fact and every discovery casts a light beyond itself, and the extent to which this light is perceived depends upon the man."—GORE.

Modern Analysis.—The influence of the application of modern methods to analysis has profoundly modified this branch of chemistry. Until this influence was directly brought to bear, the latter was incomplete, and to an extent empirical in its procedure.

The presence of correct methods of analysis is so essential to scientific control that the branch of chemistry has taken on a new significance in works practice.

Analysis was first placed upon a definite basis by Gay-Lussac and Berzelius. In the early development of chemistry, it played an important part. Regarded in latter years as an art rather than a science, it ran a more or less isolated course, having little in common with the general development of general knowledge. Rivot, Fresenius, and Rose practically limited themselves to detail in manipulation and the general conditions of correct working.

During more recent years this position has materially changed. A detailed knowledge of the underlying principles of precipitation, etc., has modified the entire position, and analysis in its new guise once more occupies an important place in relation to general chemistry. This change has been fully described by Ostwald in "Die Wissen-

schaftlichen Grundlagen der Analytischen Chemie," Leipzig, 1908 (translated into English as "The Foundations of Analytical Chemistry," 1908). Reference may also be made to "Qualitative Chemical Analysis," Vol. I., Theory, by J. Stieglitz (Century Co., New York).

By an application of the law of equilibrium to the reactions involved, the conditions under which precipitation may be complete or incomplete were made evident, and the methods to be pursued, in order to bring this operation to practical completion, were indicated. This review of the question of analysis in the light of modern theory has caused it in its many branches to take to itself a new significance, and play a more important part in the science of chemistry, supplying an efficient method of confirmation for theory, and in a way which is brought to the notice of all workers.

No more satisfactory example of the advantage of the application of theory to practice could be found. It indicates in a most definite manner the advantage of examining processes, whether they be industrial or analytical, from a standpoint of theory.

More general information may be gained on this point by studying the "Theoretical Principles of the Methods of Analytical Chemistry," by Chesnau (translated into English by Lincoln and Carnham, 1910). In this work will be found indications of research, which is still necessary in connection with the influence of the physical state of precipitates upon their purification by washing, irreversible reactions, double decomposition of salts, and the general study of the reactions met with considered from the ionic standpoint.

Technical Analyses.—When it is impossible to utilise ordinary methods, it is sometimes possible to substitute for them a kind of small scale operation,

which conforms to those utilised in large-scale work. Thus results can be checked in advance, and an idea obtained as to the way large scale operations will proceed when the same conditions are followed. In time, such methods of control become particularly useful, especially when, by practice, the results obtained can be interpreted correctly.

The conditions under which these empirical tests are carried out become in some cases very involved. This can be appreciated by comparing the standard method of tannin analysis in use to-day with the recognised method of twenty years ago. Also by observing that the conditions set out as standard in Europe are not acknowledged in America in all their detail. Yet, such is the belief in the utility of these methods, that thousands of tons of tannin materials change hands on a basis of the results obtained in the laboratory.

In empirical analysis, the results must necessarily be expressed in terms of an arbitrary standard. In the setting out of details for a recognised process, which will be acceptable to all those interested, the scientific method often plays a considerable part, and chemists of high standing have not hesitated to devote their time to the elaboration of conditions, which are most favourable to success, although these are not understood in their nature, but only in their influence.

All such processes are therefore subject to improvement by further trial and experience, by which means their technical significance is increased.

When the beginner selects a process, which has not hitherto given satisfactory results, he must look, in the first place, for the causes which in the past have led to uncertainty. He must search for influences which give rise to incomplete precipitation, and try and find out the action of any substances present, which may interfere with the normal course of the

reaction involved. The investigator must then determine the exact nature of such disturbing influences by direct observation or experiment, and attempt either to eliminate these or to allow for their action in some way or other. There are a number of recognised causes, which may lead to inaccurate results, and the experienced analyst will first make certain that these are not causing irregularities before he seeks for other reasons.

Work of the Analyst.—The analyst, who works with his brains as well as his hands, may reasonably expect to improve processes, or even to devise new ones, which his knowledge leads him to believe will give better results. He finds a source of inspiration in such out-of-the-way materials as flue dusts, residuals, and other seemingly useless products of the works.

The scientific examination of such materials often leads to important results, and it is the province of the analyst to make this special kind of research his own. The more general his knowledge the greater chance he will have of benefiting by his research, and the more valuable will his suggestions be.

When he possesses an original turn of mind and works with skill and a knowledge of chemical operations in general, his work will influence most branches of chemical activity.

There can be little doubt but that the future will call for an increased efficiency in the works laboratory and that analysis will become more complex and difficult. While repetition work will be performed by those who have little knowledge of chemistry, the analyst proper will find that he is called upon to perform a higher grade of work, and that he will be expected to supply new methods of analysis where these are imperfect and even to work out new ones when the existing ones are unsatisfactory.

The literature connected with analysis is particularly voluminous, widely dispersed, and somewhat scrappy. A search into this will soon disclose some point which still calls for further attention, and more or less original investigation.

By comparing standard processes with others, which are comparatively unknown, useful information can generally be secured.

It is often found that the use of a recognised process may be extended in a new direction by the introduction of modifications in detail. The Kjeldahl method of estimating nitrogen is a case in point.

The young analyst should be continually on the look out for improvements in existing processes, as these may be suggested by his own experience. This search for hidden difficulties and errors will improve his general standard of working and impart to it an added significance.

Defective or discarded processes may be re-examined with a view to their improvement, especially when it is observed that they possess certain advantages over present methods which could be utilised if defects in other directions were eliminated.

Volumetric analysis, gas analysis, gravimetric analysis, empirical methods like the International method of analysing tannins, all call for further investigation and improvements in detail. The whole subject is one of special interest in the present day, when works efficiency so largely depends upon control, and when so many new methods of producing results are constantly being introduced, each calling for new conditions, which must be followed in detail.

The experience gained in following up such work amounts to a sound training in simple research. Skill in the laboratory means added manipulative power, and an increased speed in working for accurate results.

PART II.—PRACTICAL RESEARCH

"Whoever could make two grains of corn, or two blades of grass, to grow upon a spot where only one grew before, would do more essential service to his country than the whole race of politicians put together."—SWIFT.

CHAPTER IX

AIMS OF PRACTICAL SCIENCE

"To spend too much time in study is sloth. . . . To use them (studies) too much for ornament is affectation. To make judgment wholly by their rules is the humour of the scholar. . . . There is wisdom above them, and beyond them, won by observation."—Francis Bacon.

Economic Gain.—From this chapter onward, research is considered in its practical aspect. Facts and theories are regarded as a kind of raw material, which is utilised wherever possible. In practical research, the main object aimed at is to gain economic efficiency, by securing new, or better, methods of working in large-scale production, or by introducing new and useful products.

In works practice (for such operations are generally carried out in works) past experience is first looked to, as a guide. Whenever possible, this is supplemented by scientific knowledge and investigation, and then greater efficiency, from both a physical and economic standpoint, can be secured.

When entirely new processes are brought into operation, past experience may be of smaller account. Where plant construction, and practice, are entirely new, common sense must largely replace experience, and this, combined with any available data, must be relied upon to bring success.

When scientific knowledge is useful, it finds its true meaning. Combined with actual experience, it becomes a new fact. In its absence, speculation and controversy are alone possible, and works practice is empirical. The important point about a scientific fact is its usefulness.

Scope of Practical Research.—It has been recently stated that some 400,000,000 of the world's inhabitants spend their lives in factories or workshops, and that within a few years this number will have increased to 500,000,000, mainly through industrial expansion in India, China and Japan. It is therefore possible to form a rough estimate as to the number of chemists, which will be required when industry is organised on scientific lines.

Assuming that only one chemist will be required for every thousand workers, and for one-fifth of the total number employed, there would be a call for 80,000 trained chemists. It is impossible to conceive the changes that such a concentration of scientific energy would bring about, not only in actual practice, but in the conditions which surround working conditions. A gain in efficiency amounting to 10 per cent. on the average would be equivalent to the labours of an extra army of 50,000,000 workers.

By comparison with such an organisation, our present efforts are of little account. A few years ago the writer estimated that a body of *trained* chemists numbering 600, could easily be utilised in the British textile industry alone (see "The Research Chemist in the Works," published by the Institute of Chemistry). This estimate was based upon the condition that one chemist should not deal with plant represented by more than £500,000 of capital. Any one with practical experience will allow that an even larger number could be easily absorbed provided that they were capable of original work.

Results obtained in Practical Research.—The young chemist will succeed in the industrial world when he improves past practice and secures better conditions of working. Later on, he may turn his attention to the working out of original processes

for which a wider, and more complete experience is naturally required.

From the first he must be prepared to find his results and conclusions judged from a standpoint of utility and works practice.

This means that a new condition is introduced into his work. The economic factor stares him in the face, and demands that his results shall be immediately useful. Further than this, that they shall be more useful than those already practised.

The student will have been accustomed to thinking in terms of static research, for he will, in all probability, have been in contact with those who regard research from a purely academic (or static) point of view, relying upon others to complete discovery, and extend their results to the point where they become useful.

The practical investigator has no such refuge. He is faced with the added responsibility of securing practical results. In his new world "every hand that trembles is pushed aside," and the uncertain worker rapidly finds his level.

Another new condition has to be faced. The publication of his results is barred, unless this takes place through the Patent Office. The value of his work rests in secrecy, and not, as in academic or static research, in publication.

In these two important directions the work of the practical investigator differs materially from that of the academic one, who is rarely called upon to consider the economic side of research, and whose main chance of recognition rests in the widest possible publication of his results.

As a matter of fact, the investigator should always proceed as if his aim is a practical one, and when his results are not of this order he should record them for the use of others, who may complete discovery by their use.

Academic and Practical Workers.—When this is realised, it will be seen that general efficiency is clearly dependent upon co-operation between the different branches of chemical activity rather than in the forcing of their individual aims and ideals, which are, of course, mainly determined by surroundings and tradition.

The recent war has brought scientific workers, who were living in different worlds of thought and experience, into a more reasonable contact. This, in its turn, has brought about a better understanding. The college worker, has learned much of the nature of industrial investigation. He has been led to the conclusion that this work is often exceedingly complex, and that the practical man has to secure results under conditions of working which would be considered impossible in the laboratory.

He has observed, that processes in the works are often so changed in outward appearance, by design, or compulsion, that they hardly seem to be of the same order; that the main difficulties met with in large-scale production have no counterpart in the college laboratory. On the other hand, the practical investigator has gained an increased knowledge of the work performed by academic workers where the substances used are chemically pure, and products are prepared on a basis of grammes instead of tons.

Sir J. J. Thomson recently remarked (Chemical Society's Annual Dinner) that his war experience had brought to his notice the fact that laboratory work was only the beginning of research, and sometimes its least difficult phase. He had been greatly impressed by the difficulties, which had to be overcome before work could be undertaken on an economic scale.

Only those who have had long experience in such work can fully realise what these difficulties really are. It will be remembered that the inventor of the

steam turbine had hardly overcome his practical difficulties before his patent expired. Still greater difficulties are being overcome by those, who are trying to place the gas turbine on an economic basis. The added difficulties are innumerable in practical research, each of which must be overcome before success is achieved. In this the work of every one is involved, and only by the closest co-operation can success be realised within a reasonable period, or with any certainty.

Practical experience alone can give an idea as to the relative value of static and dynamic research. The condition, which prevents publication of details, has left those who confine their attention to static research in the dark, as to the greater portion of that, which is dynamic.

Occasional visits to a works cannot give the required information. An example illustrating this point will be found every time an experienced and practical investigator is called upon to report upon a new process. In such a case, a month's personal and close examination into working conditions will generally be necessary, even when he is conversant with the practical conditions governing the working of the process in question.

When a scientific commission undertook to report upon the 10,000 h.p. experimental plant erected by the Badische Company to demonstrate the Birkeland method of fixing nitrogen from the air, it is known that they found it necessary to take entire charge of the running of the plant for such a period, before they felt that they could claim that their insight into the process was complete enough for them to report.

Additional Responsibility.—The additional responsibility involved in practical research is widely observed. In a works the beginner realises almost

immediately that his knowledge of chemistry, even when this includes an experience in laboratory research, is of small value in itself. At best, it is a skeleton framework, which by laborious work he has to fill in, until the structure is complete. Only in its use can his knowledge be of any value to him, and in this further experience many other things beside chemical knowledge are necessary.

As the years roll on, and experience comes to supplement knowledge, he will settle down to work on general lines, making use of his chemical knowledge whenever possible.

Theory and laboratory practice will in time assume a modified significance brought about by their use in actual practice.

When all has been achieved by chemical knowledge and the use of theory, difficulties remain, which still stand in the way of progress. The chemist cannot afford to relinquish his work at this stage, relying upon others to complete it. He must face the task of finding out the way to overcome these remaining difficulties. This extension in practice must be faced by the practical chemist who wishes to succeed in his work.

" Pure " and " Applied " Research.—An estimate of the relative value of these two branches of research presents difficulties. The mere presence of such terms indicates an absence of a proper realisation of the value of practical research. The latter is not concerned with the mere application of knowledge, as this is applied in the form of generalisations or data by certain workers in " pure " research. Such terms may have been useful in the early days of investigation, although the writer doubts this. To-day, they represent an obsolete idea, better forgotten. As progress widens, and action forces further thought, their usefulness wanes. Already,

in the more modern industries, such distinctions no longer have a recognised meaning.

Teaching, Research, and Industrial Control.—The driving force exerted by practical science is the combined effort of the teacher, laboratory worker, and the chemist, who works out and controls large-scale operations.

A relatively low efficiency, in any one of these directions, affects the general position. If any one of these activities should work in a direction, which is contrary to the common good, all must suffer. The complete co-operation of all the interests involved must somehow be secured.

At some future time this difficulty will no longer exist, and then the student will pass from the college to the works without any material change in his ideas, or methods. For this to happen, each section must form a correct opinion of the value of the work of the others, and conform to a general scheme of progress.

When the young chemist can pass from one stage of his experience to the other, and his trained eye and reflective mind has not to consider an intermediate one, in which, by self-instruction he must readjust his ideas, a great step will be achieved.

Knowledge and the Practical Chemist.—The practical chemist, possibly making use of static knowledge, brings about the completion of discovery. Accumulated knowledge has little value until it is utilised.

The zenith of activity is reached when a man is enabled by past experience and a natural, or acquired ability to make the best use of any knowledge he may possess. It is then that he experiments with a freedom from error, and is practical in his outlook.

The unqualified acceptance of the decisions, and opinions, of a man, whose knowledge greatly exceeds

his practical experience, should always be guarded against. Such decisions should always be confirmed, before they are brought into large-scale practice. Otherwise, ill-balanced action will result, as in the case of Hamlet, of whom it was said " that he was so amazingly clever that he made a mess of his own life and the lives of those he loved."

The Chemist and Industry. — It is doubtful whether any other worker in science has to meet a more varied call upon his services, than the practical chemist.

The problems he has to face, and overcome, are innumerable, and they vary in their nature to an extraordinary degree. Each, and all, have to be considered. Sometimes these may call for a knowledge of engineering practice, or the conditions may be purely physical in their nature. Surface action, absorption phenomena, and many other equally obscure causes may interfere with his progress and conspire singly, or collectively, to stay his hand, and complicate his work. The writer remembers times in his experience when it was necessary to drop chemistry, and advance on lines where engineering, or other outside conditions had to be overcome, before any progress was possible. This is probably the experience of all, who have been engaged in large-scale production. The ordinary straightforward conditions, which apply in academic research for the most part, must not be looked for in industrial work.

In many instances the causes, which give rise to results, have first to be recognised. The field of industrial research resembles that of a battle rather than the ordered parade ground. In the end, a position will possibly arise where a process can be controlled on scientific lines only in certain sections, the others being controlled empirically. The latter

methods may seem strange to a chemist, who has always worked with pure chemicals and in glass beakers, yet they serve their end successfully, overcoming difficulties, which would otherwise be fatal to progress and hold up the utilisation of that part which is already run on more certain lines, and which conform to known fact and experiment. As a temporary measure, their use is justified by the results obtained in the past.

The experience required by the practical chemist is therefore wider than that of the academic worker. Quick decisions must often replace considered action, as this is based upon prolonged experiment.

When a process cannot be explained by present knowledge, it is quite impossible to hold it up for this cause. The best must be made of empirical knowledge, and with caution progress must rest on such a structure until more certain information is available.

Were the practical chemist to confine his attention to those processes, which can be worked on strictly scientific lines, half his usefulness would be lost to industry. When the academic worker is faced with mixed reactions he must overcome these, and resolve them into their simpler factors, or throw down his tools. The practical chemist has to secure useful results in the presence of many unknown conditions, which are there because they have not yet been reduced to order. He is a pioneer, always working in advance of scientific knowledge. Like Shackleton in his latest attempt to reach the South Pole, he holds that "A man must shape himself to a new mark directly the old one goes to ground."

Knowledge of Previous Research.—From the confused mass of information published in scientific and technical journals, and text-books, the practical investigator must select that part, which is likely to

be useful to him, and to so arrange it, that it can be referred to.

The practical chemist should not hesitate to consult others, who have a more special knowledge. A second opinion is too rarely sought in the starting up of a new process. Experience should be utilised, from whatever source it comes. The organisation of a works is incomplete, unless every possible advantage is taken of all available knowledge. The cost of an opinion is small beside the risk of the loss, which may follow the erection of an ill-considered plant.

Where operations must still be conducted on empirical lines, or where success depends upon questions of detail, it is especially necessary that every possible aid to correct working shall be sought for, and utilised.

Research and Utility.—In time, experience leads an investigator to select lines of research giving useful results. Instinct and common sense lead one in the same direction.

In an active centre of industry there is little time to waste on research, which is undertaken with the idea that "something useful may turn up." Such research is too often sterile.

There is little object in an experienced investigator setting out to duplicate the work of others, where nothing but the recording of a few more physical constants, or minor facts, can be looked for. These are soon swamped in the sea of existing fact.

Changing the Process of Manufacture.—So many conditions, and possibilities, have to be considered before any radical change in methods can be introduced in large-scale production, that progress often seems slow to those, who do not fully understand the position which has to be faced.

It is better to work carefully, than to make a rush at things, trusting that somehow, unknown condi-

tions will not be met with, and interfere with progress. The added difficulties introduced, when an improvement is effected in two stages instead of one, should stay a man's hand, and make him reconsider his programme as fresh fact comes to light.

A change in method often means a temporary delay over the whole plant, even when the greatest care is exercised. Also when investigation is successfully utilised on a section of the plant, this may introduce fresh difficulties elsewhere. Workmen, who have been engaged for years on a definite routine, naturally hesitate when they have to perform new and strange operations, the reason of which is not evident to them.

Where more than one change is introduced, it is sometimes exceedingly difficult to discover which improvement is responsible, when defects develop a considerable time after the changes have been made. The young chemist should go slowly, and not get into the habit of changing methods simply for the sake of doing so. Delays in manufacture caused by changing methods necessarily reduce output and this may outweigh any advantage gained in method.

The possible after-effects of any change must always be carefully considered. It is no uncommon thing for an immediate result to be nullified by changes which take time for their completion. It is in this direction, that the inexperienced worker may fail. Where it is necessary that action be taken without a reasonable knowledge of the results which may follow, past experience is generally the only guide. Results must be watched at every stage of manufacture.

The best results are only obtained, when every advantage is taken of all possible sources of information, be this theory, experience gained during the laboratory stage, or past experience in the works.

The last is often the best guide, as it naturally stands closer to actual practice.

Relative Efficiency and Cost of Production.—In practically all cases of large, or economic, production in a chemical works, comparison can be effected by the relatively simple expedient of expressing the result in terms of labour. The practical investigator is concerned with the cost of production of a material.

In a wide sense, research is either concerned with the production of some new material, which can economically replace existing ones, or else with the improvement of existing processes so that they require less labour to produce the same result.

In practice, all operations can be referred to labour in some shape or form and the variation in the market value of skilled and unskilled labour renders it imperative that these should be compared on a basis of wages. This applies to each, and every stage, of manufacture, from the obtaining of the primary raw materials to the finished product.

The laboratory chemist may set up a basis of comparison on lines of relative efficiency. Only when all other factors remain constant can this be applied to practical work. Where an alteration in method entails changes in labour conditions, this must be allowed for when efficiency is determined.

The following examples will make this point clear. In the first case, two processes for the manufacture of the same final product are working side by side. Different raw materials are utilised, and varying proportions of labour, skilled and unskilled, are needed for the working of the same. The plant in the one case is simple, in the others complex. To form an estimate of the comparative values of these two processes it is necessary to make allowance for these additional factors.

In the second case two processes of manufacturing are available. In the laboratory the first gives an efficiency of 90 per cent. on theory, and the second, 70 per cent. On this information alone the former is the better one. In practice this order is reversed because the cost of raw materials in the former case exceeds that of the latter by 60 per cent.

The economic efficiency of a process is therefore the real indication of its value. Equally, the practical value of a mathematical expression, which is utilised, can be expressed in the same way. The same may apply to a set of curves, or an academic investigation.

Thought and action are, in a way, capable of comparison, when their value is declared in economic terms, an operation which is sound in an experimental science.

There are other factors which play a part in the working of a process. For instance, the life of the plant is often an important item in expenditure. It is obvious that if one process can be carried out in such a manner, that the plant renewal account is less than in another, this can be allowed for, as at the end of each year a proportion of the original cost of a plant must be written off and added to the cost of production. This may also be expressed in terms of labour.

The object in view is the same in all cases. All are concerned with the obtaining of more efficient methods as these are represented by labour expenditure in its widest sense.

Thus the physical efficiency of a chemical process, however satisfactory in itself, will not enable one to form an opinion of its value.

Interest on capital, cost of distribution, etc., may not directly concern the investigator, although they may be materially modified by his endeavours. If on any given plant the chemist can so modify prac-

tice, that the production is doubled, this means that general charges may be halved per unit of production.

Research and Industrial Operations.—It will be seen, that all operations connected with the economic production of useful material can be reduced by such means to common terms of comparison. From this standpoint, the value of academic research must also be expressed in terms of its utility, and in this way brought into the same scheme of comparison, and its value declared in equivalent terms.

It has been stated that "science is a branch of industry." At some future time, a stage may be reached where it will be more correct to say that industry is a branch of science.

Science and Industry.—When a manufacturer takes up a new process, or engages in a new manufacture, he selects methods of production which offer special advantage. This choice is primarily made with the object of securing a better return upon capital. The practical investigator, approaching the position from the opposite direction, has the same object in view. Both ultimately meet on the common ground of production. Both attempt to secure the same result by reducing the labour involved.

The teacher aims at instructing his pupil so that he may work with greater advantage. The research chemist carries this process on a stage by providing a further supply of knowledge. Others then consider the problem of economic production. These united endeavours give a real meaning to science. These interests then join hands with those who provide raw material on the one hand, and look after the distribution of the final products on the other.

At the heart of every completed discovery is the wish that it may be useful. There is little else

that matters. At a later stage, it will be shown how the conditions which govern research may be set up in the works proper, and the influence of science usefully extended, a process which will not stop until the whole of industry is covered.

CHAPTER X

PRACTICAL INVESTIGATION AND THE PERSONAL FACTOR

" Science, and the applications of science, are united together as the tree and the fruit."—PASTEUR.

Scientific Knowledge and Practice.—The worker in pure science claims that he is entirely concerned with the discovery of new facts and generalisations; also that, in these days of specialisation, more is not possible. The practical investigator takes up the task where the academic worker leaves it, and carries it on to its logical conclusion. That discovery is mainly divided into two stages is entirely due to this convenient division of labour, which depends upon the fact that the human intellect is unable, except in exceptional cases, to complete discovery in one stage.

In the main the successful workers in pure science are those who have a practical aim, for then their results can be utilised without delay. When the use of knowledge is delayed through the fact that it is not directly connected with practice, the position of a worker in pure science is less definite, and subject to the verdict of future workers rather than present ones.

Recognition of Research.—The application of knowledge brings an instant recognition of the value of research. The knowledge that their labours may have a useful ending acts as an incentive to all, who realise the true aim and object of scientific investigation.

Huxley pointed this out quite clearly: "I weigh my words," said he, "when I say that if the nation could purchase a potential Watt, or Davy, or Faraday at a cost of one hundred thousand pounds, he would be dirt-cheap at the money. It is a commonplace that these men produced untold millions in the narrowest economic sense of the word."

It is the fate of all research either to have its worth declared in terms of direct utility, or fall into the background of half-remembered fact. Faraday was once described as a man who was always playing with wires. Yet because his aim was practical there is not a civilised race, which has not benefited from the nature of his discoveries, or an investigator, whose work has not been made more easy in some way, or other, by his discoveries.

The Progress of Research.—The results, which follow in an ordered sequence, are well illustrated by the discovery of the miner's lamp. Davy first observed that a hydrogen flame would not pass through a long glass tube, when the bore was sufficiently restricted. Following this, he found that a shorter tube would give the same result when the diameter was correspondingly restricted. By further experiment it was shown that, by reducing the aperture still further, the length of the tube could be so reduced that a closely woven wire gauze could take its place.

A man who confines his attention to academic research must, in most cases, leave to others the task of completing discovery. Davy was not an investigator of this sort. He carried his research to the stage of usefulness, and as a result the miner's lamp was produced. He dealt with both the first and second stages of discovery, and his research was of immediate service. His research was carried to its full achievement.

Both physical and logical discovery are involved in general research. In cases where both cannot be secured, a skilful use must be made of observed facts. Reasoning must be preceded by empiricism, in order that sooner, or later, the former may be brought into action. A preparatory process is necessary in order that the reasoning may be profitably employed.

The Practical Sense.—Many leading chemists have carried their work through both stages of discovery, but in such cases they have been men of commanding mentality or great experience. For instance, Pasteur's work was of so practical a nature that his results were immediately useful. Further than this, *he utilised them himself*. He never stopped to consider whether his work was "pure" or "applied"; probably the thought never entered his mind. When he was called upon to save his country's interests, and clear some great industry from its disabilities, he at once placed his services at the disposal of those who were in trouble. Like Faraday, he refused financial reward. He gave with both hands, and received during his lifetime a recognition of the extreme value of his labours. A true worker in science, he turned his attention with equal success into any quarter, which seemed to require his aid, seeking to place his talent and ability at the service of others.

In a general way, science has been termed a branch of industry. It is the work of men like Pasteur, which has given science its true position.

The student will remember that if he desires to see the results of his labours, he must work in practical directions. Onlv when discovery is dynamic is it evident that the work undertaken has a real value.

Invention.—The superior value of knowledge,

which has a practical value, is seen in our Patent law, which enjoins that protection shall only be granted to a discovery which can be usefully applied When Victor Hugo held that "The ignorant man may discover, the learned invent," he probably meant the same thing.

Experience brings with it the power to work in practical directions. A great deal of useful research originates in the factory. Thus Carro's work on the cyanamides arose out of the wish to prepare cyanides on a large scale.

It is interesting to observe that Whatley, in his "Elements of Logic," holds that "wherever the term discovery is applied to him who is the author of it, that this is particularly deserved by those who skilfully select and combine known truths, especially those which have been long and generally known, and where they elicit important and hitherto unthought-of conclusions." "Theirs is the master mind," said he. There is no need to work in fantastic directions to obtain great results. Whatley also laid down that "men of inferior powers may sometimes, by immediate observation, discover new facts and thus be of service in furnishing materials to others, to whom they stand in the same relation as the bricklayer, or stone quarrier, to the architect." He laid special stress upon the value of work derived from "data which had been in everyone's hands for centuries."

Thus such workers as Faraday or Pasteur, and such thinkers as Hugo or Whatley all emphasise, —the workers by their results, and the thinkers by their reasoning,—the extreme importance of the practical sense. Another point to be realised is the fact that the greatest results are obtained by a straightforward attack, not by philandering with research, and following it into directions, which seem to offer little advantage, or reward.

Discovery and Invention.—Practical investigation calls for invention as well as discovery. As a matter of fact, the inventive faculty is always highly developed in the successful investigator, who is concerned with the practical side of his science. Invention is not always a feature of academic work. This explains why so much of it is uninteresting and seemingly artificial.

This difference in mental equipment is at the root of the distinction, which has been set up to divide academic from practical research. This also explains why a man may succeed, say, in academic research and fail in practical investigation. He has not the necessary inventive power. Either it remains rudimentary, or it has been indifferently developed by use.

The realities of science constantly react upon past knowledge. Text-books rapidly become "out of date." Theories which seemed so sure give place to others, which, in their turn, are likely to disappear. Processes are discontinued because they are replaced by others of greater utility, but they still can be utilised upon emergency if this is desired. But the discarded theory has no value as a guide to practice. It was shattered by some new observation, and can never regain its usefulness. The difference between theory and experience, or fact, is thus set out. The experience of twenty years ago may still be of considerable value to those who possess it. A knowledge of the theory of a similar period may be quite useless.

Thus the practical worker, considering things, will mainly hold to his own experience, while knowledge is so partial in its nature, and practically non-existent in certain important directions. As our knowledge increases it may be expected that the term "exact science" will be discarded and the term "relative knowledge" will take its place.

The True Investigator.—The genius is obviously the true investigator. Although scientific research is in ways impersonal, yet such a worker undoubtedly impresses his personality upon his work. His special qualities are reflected in the results he brings forward. This is certainly true in the arts. It is equally so in practical science, varying in its demonstration as art varies from science, and the fact that the personal qualifications, which bring success in the one case, are not those which bring achievement in the other. To mention such names as Newton, Darwin, Pasteur or Kelvin is to immediately recall their activities.

The working of a great mind always represents a mystery to those of lesser ability. It seems as if a brilliant intellect were directing a searchlight down the still undiscovered ways of progress, wresting from Nature's half unwilling hands the secrets of her innermost experience. Action of this nature often leads to volcanic changes in thought and practice. In other cases, the step gained is so far in advance of practice, that it can only be slowly assimilated and utilised. Such is investigation at its best.

The highly skilled investigator always seems to work in practical directions. He seems to have a clearly cut aim in view. An inferior mind cuts through a forest of undiscovered fact without having a clear idea as to where his investigations may carry him. Experience has indicated, that it is always advisable to work within one's powers, where a tight hold can be kept on experience, and results may be obtained, which can be appreciated and therefore utilised.

To survey fresh ground, and when all is prepared, to push experience into hitherto unknown regions, is truly the romance of science. But in such an adventure, the precautions to be taken, and the

which is not necessarily one able to engage upon highly skilled research, where the imagination plays such an important part. The ordinary investigator should see that his work is practical. Given this necessary qualification, he can do much by applying to new problems past knowledge, and utilising every bit of practical experience he possesses.

In the actual control of processes, he may play an important part. His very limitations may be an advantage. Much can be achieved in the direction of scientific control, when every point of detail is dealt with effectively.

For the highest work, inspiration, imagination, vision, and a fair share of that somewhat rare quality termed common sense, must be combined with industry and indomitable assurance. Not the assurance, which amounts to cocksureness, for this is a handicap to the scientific worker, but that, which comes from a belief in one's powers, as these have been proved in the past.

Common Process of Research.—It has been the aim of the writer to indicate that both academic, and practical research are part of the same system, and that equal attention must be given to each. The final expression of scientific knowledge is its usefulness, and when this is not apparent, it rests with the practical worker to make it so by further discovery.

Academic research may exhibit a novelty, which is startling in its implied significance. Practical research reaches out in all directions, and discovers in what way static knowledge may be made dynamic. It modifies important sections of industry in an equally remarkable manner.

Of late years, academic research has overrun practice. Much of it is seemingly of little importance, some of it obviously still-born. A proportion of it

possesses great significance, and this is examined and re-examined by the practical chemist until its full value is extracted.

Practical investigation controls action as academic research controls thought. Thus, the true division of research is not the college walls, or those of the research laboratory. It is something different. Research passes from one stage to the other when it ceases to be static, and becomes dynamic. Other things being equal, it is just as possible that research may reach the dynamic stage in the college as in the works. All that is asked is that it shall be useful, otherwise it must be regarded as incomplete.

When the greatest of all questions, What is Truth? is answered, it will be time to classify on their merits these two kinds of knowledge.

This new division cuts right through the fabric of research and separates what is, for the time being, useful knowledge from that, which has no practical interest, as this term is used in its widest sense.

Laboratory and the Works.—As it is necessary when standing in a brilliantly lit room, to lower the lights before the outer world can be perceived through the open window, so in the laboratory the glare of present fact may hide the greater significance of the things of the works.

The main duties of the academic worker are to instil into action a better purpose by clarifying the process of thought, and through this to place at the disposal of others matter of wide significance. Knowledge, which transcends the imagination, is of little use to the practical worker, who cannot lose touch with reality without endangering his whole position.

At the time Lord Beatty was fighting the Dogger Bank action, and the *Blucher* was just being sunk, wireless messages were coming in fast describing

the relative positions of the respective fleets. These were followed, in Lord Fisher's private room at the Admiralty, by those who were congregated round the central table, upon which a chart was set out. But Lord Fisher sat alone at his desk in one corner of the room, silent, grim, with shining eyes. The *Blucher* was being sunk to his prescription, out-run, out-ranged. So, in the struggle for industrial supremacy, the battle is often won before it is fought.

Courage and determination are qualities, which bring success to the imaginative worker. When these go with foresight and skill, the most determining results are secured.

Nothing worth having is obtained without taking risks in some shape, or form. Short of actual danger, research must be pushed to its limit. By such means competition may be met squarely, out-run, out-ranged.

Success in Industrial Research.—In tracing the cause of the relative success of some investigators and the failure of others, who seem well qualified for the act of investigation, and possess active minds, one may divide practical research into two processes—the first concerned with the discovery of suitable subject-matter, and the second with the actual carrying out of investigation on the same.

Thus, it follows, that an investigator, who fails in the first operation, will have little to occupy his attention in the second. Thus it will be seen that a carefully trained investigator may fail when he has not the power or necessary experience to enable him to work in useful directions. A realisation of this fact will explain much.

An investigator may therefore be well qualified to carry out research, and yet have little to occupy his attention. Industrially, he may be of little account.

He will certainly be surrounded by problems in the works, some of them already recognised, some not. Yet he has not the power to select those, which will lead him to success, or to separate them from those of lesser importance.

Why should one class of worker fail, and the other realise the essential points of works practice? The answer lies in the fact that something more than a knowledge of the methods of actual research is required. Preliminary investigation in the works also calls for skill, which is of equal, if not greater importance, than the investigation, which follows. This preliminary work calls for different mental qualifications; and many of those connected with laboratory practice fail because they cannot engage successfully in this work.

Originality and adaptability of thought are essential. The instinct, which we term common-sense, must be highly developed, and the true inwardness of processes must also be successfully recognised during this early stage of investigation, which is of such vital importance.

Actual research may therefore be the lesser problem, easier because the road can be generally followed by tracing the tracks left by others. Such aid can rarely be met with when the actual conditions of works practice are under review, which must be examined by specially devised and thought out means.

Life of Industrial Research.—The general activity in the industrial world, and the greater use, which is now made of the scientific method of control and development, sooner or later terminate the sole use of a new discovery. In a modern works, research is continually in progress, in order that fresh discovery may take the place of the exclusive use of important facts.

At the same time, it often happens that an improvement can be kept secret over long periods, especially when its nature is not disclosed in the finished product. or material.

The manufacturer who fails to take advantage of modern research undoubtedly meets failure half way. He cannot expect, in the long run, to keep abreast of those who are more enterprising. Organisation in other directions, which for the time being seem to offer an easy way of meeting competition, cannot give the results which modern research can inevitably secure.

A searchlight must be directed into every part of the works. Even the most simple, or seemingly insignificant, of processes must be examined, and never left until it is thoroughly understood.

Any improvement effected will automatically cheapen production or increase output (which is the same thing); a more satisfactory substance will be produced with the same expenditure of labour, or greater output of material obtained with the same expenditure. Improved methods generally mean a longer life for the plant. This again reduces the amount of labour involved and leads to a lower cost of production.

CHAPTER XI

LABORATORY RESEARCH AND WORKS PRACTICE

"*Nothing exists except facts, and acts alone are of any consequence.*"—MARSHAL FOCH.

Large Scale Production.—The successful application of research depends upon a proper system of works organisation. This point always receives consideration where efficiency is aimed at.

Naturally the best results are secured when a works is so organised that any, and every, kind of research can be rapidly utilised. The additional cost entailed, when such preparations are made, is always repaid many times over by the results obtained. When such conditions are met, the management may be certain that everything has been done to ensure success.

The details of a laboratory investigation nearly always require amendment, before it can be utilised in the works. Such modifications in procedure are inevitable in the majority of cases, owing to new difficulties, which present themselves in large scale production.

The cost of large scale working is always considerable, and it is necessary that every precaution be taken to secure suitable working conditions, from the first. This is of great importance. For instance, it may make all the difference to the running of a plant, and the cost of production if the plant can be so constructed, that it will last for ten years instead of five. Depreciation of plant is

always considered in the cost of the finished material. Where plant construction is satisfactory, a great saving in the cost of labour may result. In cases it may be reduced by one half.

Past Experience.—When works problems are under consideration, the best guide is past experience. Especially is this so, when it is connected with operations of a similar nature to the one proposed. Success often depends upon some small detail in procedure, or a knowledge of how to overcome some seemingly minor difficulty in plant construction, or working conditions.

A previous knowledge of the way similar difficulties have been overcome is of real importance. Success depends upon a right understanding of the conditions, which will ensure efficiency of working, economy of production, and a satisfactory life for the plant. Where past experience is not available, much time may be expended in determining some points of detail, and progress greatly delayed thereby.

Problems of this nature belong to the works. Except in very special cases they cannot be dealt with in the laboratory. Many of them can only be considered during the period of actual production. As far as possible, every precaution should be taken to make certain that actual production shall start with every advantage that can be secured. This preliminary study of working conditions and plant construction tests the capabilities of the industrial chemist to the utmost; and the young chemist, who can successfully meet conditions, which call for the working of a laboratory process on a large scale, may rest assured that he has made considerable progress, and incidentally gained experience, which will be of service in his future work.

Past experience, as this is represented by the

stored-up knowledge of empirical or relative fact, is at the base of many an epoch-making discovery.

Large Scale Experiment Plant.—In cases where past experience cannot be accepted as a direct guide, or where a process is so novel, that it calls for investigation at almost every point, progress is best secured by setting up a large scale experimental plant. With the working of this, knowledge may be obtained on points, which must determine the construction of the large plant, and give information as to the difficulties in the actual working. Also, it will bring to light points, which have not been recognised, when working on a laboratory scale.

The engineer-chemist (or chemical engineer) or engineer, as the case may be, will interest himself closely in the running of this intermediate plant. Thus the process of manufacture will be considered from a wider standpoint, and additional knowledge and experience brought to bear upon it.

In the case of a new manufacture, it is suggested that an experimental plant should always precede the actual manufacturing one. Time will be saved when this course is adopted, as the experience of the laboratory chemist, process chemist, and engineer chemist can be utilised at a stage prior to the erection of the large plant.

In many cases, processes, which seem to be satisfactory in the laboratory, are either useless in the works, or incapable of being applied to large scale production. Under this scheme of development, this will be recognised at this intermediate stage, and failure on a large scale avoided, as a result of the knowledge obtained, when working the process on a large experimental scale.

Examples of such failure may be seen on every side. For instance, very few of the electro-chemical processes for preparing organic compounds have

been worked on a large scale, although many give high yields in the laboratory.

Research and the Laboratory.—The important point to remember is that research only begins in the laboratory. The conditions of large scale production differ so materially from those of the laboratory that investigation must be extended into the works, and sometimes carried on there, for long periods, before success is achieved.

Where patent protection has been granted for an entirely novel process, success is often only achieved through subsequent work, as this deals with details of procedure. The original patent may even have lapsed before economic success is secured.

Success often depends upon some minor point, and the chief difficulty to be overcome is found to be connected with some small detail in manufacture, which, as it stands, may completely hold up large scale production. In such cases, it is observed that investigation has to be extended into regions where empirical working is alone possible.

It is when the practical chemist is working under such conditions that his greatest triumphs are secured. His skill in experimenting will often lead him to make full use of observation, where this is alone possible as a means of progress. The chemist cannot afford to leave this aid to progress in the hands of others. He must make all use of it.

Difficulties of Large Scale Working.—When the general lines of works practice have been settled, and the large plant erected, many difficulties which are specific to a new process have to be still considered. In many cases a considerable time may elapse before these are even recognised as playing a part in the manufacture. Years sometimes pass

before they can be tracked down by observation and successfully dealt with by the experimental method. Greatest care must be taken continually to watch the actual operations of manufacture, and carefully to investigate exceptional circumstances as they occur, following these up in every case by careful research.

It is of first importance that this should be realised by all, who devote their attention to this branch of chemical activity.

The presence of a minute quantity of an impurity may put out of action a catalytic process. The physiological action of an escaping compound, like carbon disulphide or a volatile nickel compound, may seriously delay large scale production.

The point to be emphasised, until these facts are realised by all, is that the chemist's work does not end in the laboratory, and that his investigations in the works may often be of even greater importance, and more determining in their influence.

Works Problems.—In some cases the experienced investigator may prefer to work on a works scale instead of on a laboratory one. Work of this nature must be carried out with great care and foresight, or the result may be disastrous. In exceptional cases, it may be easier to alter the condition of actual working rather than to start experiments in the laboratory on an inadequate scale. In some cases, it is practically impossible to reproduce the conditions of manufacture in the laboratory, and it is then that a decision may be come to, which leads to experiment being conducted on a full manufacturing scale.

It is not possible even to indicate the difficulties, which have to be met when this decision is made, and this always greatly increases the responsibility of the chemist.

Where difficulties are observed to exist on th plant there is a direct call for further investigatio Only by such means, can the best conditions manufacture be secured. It often happens that th difference between satisfactory working conditio and the reverse is the difference between econom success and failure. The margin, under whic success can be achieved, is narrowing down, as gener efficiency is extending. There is a definite call f an examination of all the details of manufactu which can influence production or efficiency.

Economy of Working.—Success depends upon th joint endeavours of every member of the technic staff. The laboratory chemist, process chemis engineer chemist, and works engineer all work this common end. To these may be added th consulting chemist and consulting engineer, whe important matters are under consideration. Also t business manager and the accountant may be call into consultation with advantage, especially wh the question of costs is under consideration.

Nature of Progress.—It may happen that t results obtained by the joint endeavours of the st may be so novel, or useful, that they practical introduce a new process or material, for whi there is an immediate use. In such cases, it may n be so essential that a high state of efficiency shall present.

Where such favourable conditions exist, it possible to work for the time being on lines whi are obviously not permanent, or which could tolerated under conditions where competition h to be faced. Where this is so, further time available for the working out of details which alo can give success. The advantage of being first the field is self-evident.

Such conditions, however, are rarely met wi

In the ordinary run of affairs, comparatively perfect conditions of manufacture, and efficiency of production, have to be secured from the very beginning.

Too much attention cannot be paid to any source of additional knowledge, which can favourably influence the conditions of manufacture.

Where attention is not paid to this point, it has been observed that the best endeavours of the laboratory chemist may come to naught, and the practical application of important research may be delayed, or even prevented.

In a modern works, the chemist brings his experience to bear upon actual conditions of manufacture, and, working in conjunction with the engineer, examines in detail every stage of manufacture, with a view to its improvement.

Chemical Knowledge and Works Practice.—The practical chemist must be ready to utilise his knowledge in the widest sense. Otherwise work which should rightly fall to his consideration passes to the engineer, or works manager.

When the chemist restricts his interest to points which are distinctly chemical, and takes little interest in the general affairs of the works, the influence which should be rightly his, will pass to the engineer, who, as a consequence, will occupy a position of greater responsibility. For some mistaken reason, the chemist is apt unduly to restrict his interest, with the result that his influence suffers, and he only secures a secondary place in the works organisation.

This often occurs where the manager of a chemical works is an engineer. Although this may in some cases (where the main work is connected with the plant rather than with the process) be an advantage, yet there are many cases where it is better that a chemist should be in control.

The writer does not know of a case where an engineering works is managed by a chemist, but of many where a chemical one is run by an engineer. There is a call for the chemist to take a wider interest in the affairs of the works.

He must consider such matters as cost of production, and be able to understand a cost sheet. He must be able to see where a further saving can be effected in the cost of manufacture. But much more than this is required of him, before he can efficiently take over the management of a works. The chemist too seldom realises that he must be prepared to undertake work in any direction where his special knowledge can be utilised.

Apart from this point of a wider experience and applied application of chemical knowledge, the relations, which exist between the chemist and engineer in a works, are generally of a cordial nature, each striving to secure the advantage to be obtained from his particular knowledge and experience, and then joining hands in the more general aims of industrial service.

Additional Qualifications.—If the chemist is to secure his right position in the works, his knowledge must be as satisfactory, from a works point of view, as that of the engineer or the business manager.

A man may be sure of his work in the laboratory, have a sound knowledge of the principles of chemistry, being fully qualified in the same by examination, and yet he may be of little value in the works. This is due to a want of those additional qualifications, which alone enable a man to hold his own in the industrial world.

Common sense and businesslike habits are necessary to success. A man must also possess the "works sense," which enables him to follow the most

complicated manufacture with comparative ease, and to understand its essential importance.

The engineer receives a training in the shops, as well as in the college, before he is considered to be a trained man. The medical student comes into close contact with the greatest of the practical surgeons during his college course. Concurrently with his lecture work, he has the opportunity of observing the practice of the hospitals, as carried out by the most skilful of the practical men. The chemical department and the works are generally miles apart, the influence of the one on the other being in many cases a matter of form.

When a student enters a works with little idea of the nature of the duties involved, he is in a different position from the medical student, who commences practice after his hospital training.

This distinction in the case of chemistry is mainly due to reasoning, which has led those in authority to assume that the chemistry of the works is so different from that of the college that no attempt can be made to train a man in the former; and that a better plan is for him to enter the works with a sound knowledge of college chemistry, and then, by a process of self-training, secure the further knowledge, which will alone make him useful in large scale production.

Where research is regarded in its widest sense there is no call for this artificial distinction, but until some steps are taken to bring the chemist's training more into line with that of the engineer or medical man, it would seem that the present system must continue, with an undoubted loss in practical efficiency.

It should not be impossible to arrange a college programme, giving the student a fair idea of the conditions, which will govern his future work, though this is not possible while the standard is maintained

that the chemist's training should be a purely laboratory one. This naturally impresses the student with the idea that the chemist's work in the works will be of a similar nature. There are higher and more difficult duties for the chemist in the works, and an attempt has been made in this work to indicate their nature, and to an extent, their relative importance. Only when this important fact is realised in the college stage will chemistry exert its full influence on industry.

At some future time a standard will undoubtedly be established, which will be equally stringent on both academic and practical lines. If the medical men have overcome this difficulty there should be no great obstacle in the way to a similar advance in the chemical training of students, who are being prepared for the industrial world. A little more attention to this point would improve the position of the student as he enters the works, and enable him to take his place beside the engineer with greater advantage to himself and chemistry in general.

It is not easy to indicate in words the additional qualifications, which must be possessed by the successful industrial chemist. Success comes to the man who, in addition to a sound knowledge of his science, has a knowledge of affairs. This must be backed up by clear thinking and high aims.

Given these, and the power of realising the conditions, which obtain in a chemical works, the chemist can enter a works with the assurance that he will be well received, and that he will have a reasonable chance of success.

Where he does not possess these qualifications, he may expect to fail in securing for himself and his work the maximum advantage. By self-instruction and by keen observation of the work of others he must still gain that knowledge.

Chemical Engineering.—It is seldom that a man can combine the experience and qualifications of a first-class chemist and that of an engineer. Nor, is it possible for a so-called chemical engineer to be equally at home in the application of both these branches of works experience.

By long experience, a chemist may acquire an engineering knowledge, which will enable him to understand and design plant, and this special knowledge may stand him in good stead in his work.

He may reach a stage where he can direct generally the work of engineers; but engineering will always remain a secondary subject for him, and he may more properly be described as an engineer-chemist, rather than a chemical-engineer.

In ordinary cases, the most that can be expected is that a chemist shall have sufficient acquired knowledge of engineering to enable him to deal intelligently with plant construction, when, say, a new works has to be designed, and that he can direct draughtsmen, and those who have a more complete knowledge of engineering detail.

Where a chemist is manager of a works it is advisable that the assistant manager should be an engineer, or *vice versa*. It may be repeated that the best results are obtained when a chemist and engineer work in the closest harmony, each realising the strength of the other, and admitting the presence of the special qualifications, which are complementary to his own.

Works Control.—It will be generally allowed that the instinct for control has been more widely developed in the engineer than the chemist; and it seems obvious that this difference is largely due to education and method of instruction.

Those who take up chemistry as a profession will do well to take all precautions to overcome this

narrowing influence, which somehow our chemical training seems to engender.

The future investigator must take an interest in general affairs, and aim at a wide outlook from the day he enters the college. He must realise that if the chemical industry is to be run by chemists, he must be prepared when this opportunity presents itself.

The war has greatly increased the chemist's influence. His services have never been so important, or so generally recognised. Working with the engineer, he has undoubtedly saved the country from invasion.

The chemist must work for this same supremacy in times of peace; and gradually the ability to engage successfully in practical work will bring with it, a greater recognition of the services which he can offer to industry.

Engineering has obtained its position of unrivalled supremacy by the practical utility of the results obtained. In the short space of a generation of workers, electrical science has done the same. Chemistry must follow in the same course. It must be revitalised. A science progresses in the ratio of its general usefulness, although this is not always realised by chemists. In order that chemistry may become, and remain, one of the great professions, it must direct its energies in every conceivable manner to the improvement of the operations of everyday life.

A mere manipulation of the methods of research will never secure this position. Success lie in a different direction. It is always practical, even its theory is practical—in its effect. This quality is only acquired when the investigator is prepared to take a wide outlook.

Laboratory research represents the first chapter in the history of an experimental science. The laboratory is the cradle of ideas, which grow and

CHAPTER XII

WORKS ORGANISATION

"It is only by the combination of the man of thought, and the man of action, of those who conceive the plans and those who carry them out, that great and fruitful results can be obtained."
—Admiral Sir Rosslyn Wemyss.

Conditions of Manufacture.—The running of a successful works calls for the highest skill. It demands a full use of past experience and personal initiative, together with a foresight, which anticipates troubles and secures the even running of plant at its maximum production.

This can only be achieved in a large works by the closest co-operation between the different members of the technical staff. Every department must be equally well organised.

The manufacturer's opinion of the scientific method is usually based upon his own experience, and not upon newspaper articles; nor does he pay much attention to the opinion of those who have little works experience.

The British manufacturer has undoubtedly neglected to make full use of the aid which science can bring to industry. The responsibility for this has not been entirely on his shoulders. He has not always been supplied with the right kind of chemist. His early education or tradition has also given him little incentive to experiment in this direction. The most powerful weapon, which has been placed in his hands, has, for a variety of reasons, not been properly utilised.

The manufacturer has been accused of doing little but "manufacture millionaires and slums." On the other hand, he has been represented as neglecting markets and losing opportunities. The fact is that a manufacturer must be able to dispose of his product for a sum, which will cover the cost of production, and yield a return upon the capital invested. When he considers the advantage of securing the aid of chemists, he must first of all calculate the cost involved compared with the advantage obtained. Only where he is convinced that the result will be satisfactory can he be expected to take action.

He knows that the engineer can produce machines and erect plant which will serve their purpose. He knows that the architect will build a factory which will reasonably cover requirements. He has no direct guarantee in the case of a chemist, unless he be a specialist, who has had considerable experience in practical investigation.

The chemist does not offer his services in kind. He does not, as a rule, suggest a better building or a more efficient machine. He offers his trained intellect, a knowledge of the work of others, and any experience he may possess in works practice.

The chemist must convince the manufacturer that it is more efficient to work scientifically; that a scientific control will give higher yields and a better product. That the cost of obtaining superior results is less than the value of the advantage gained. Where this is proved, there is always a distinct call for chemists.

Where it is observed that a manufacturer after trial does not give full consideration to the claims of chemistry, some chemist is often at fault.

The latter must demonstrate in a definite way that he, of all men, has the power of obtaining results without a substantial call for further capital. That,

by investigation in the laboratory or the works, processes may often be improved by merely altering the conditions of manufacture, or the raw materials used. The chemist must show that he creates capital out of brain power, instead of supplying new machinery which will give a higher return upon capital.

The Chemist's Work.—The experimental chemist is only indirectly concerned with the analysis of raw materials, or the testing of finished products. His aim is to improve methods of manufacture, or suggest new ones; to bring manufacturing operations more under control.

The testing of raw materials and finished products is essential, but the works, which confines its attention to this elementary application of chemistry, loses most of the advantage which chemistry can bring. Analysis, in this case, is merely a utilisation of chemistry, where action and procedure are mainly routine, or connected with control.

Manufacturers, who have made full use of science, have described their experience. Thus, at the last meeting of the British Association, Sir Robert Hadfield stated that in their own works they thought they knew a good deal about fuel combustion, but when they got real scientific men to investigate the subject they had, in a couple of years saved ten times over the amount expended upon the investigation (*Times*, September 13th, 1919).

Many cases are known where equally successful results have resulted from properly conducted investigation. When a manufacturer realises that such results can be obtained, the whole position of the chemist in the works changes, but such results are not obtained by the analysis of materials, but by the application of scientific knowledge.

Still many do not realise that the results obtained may be capitalised, possibly on a ten years' basis.

The chemist creates capital, and thus reverses the ordinary procedure, where interest is sought upon capital invested. Thus, the goodwill of a firm may be greatly extended by the aid of the chemist, and the value of the undertaking correspondingly increased.

When both the manufacturer and the chemist realise the powerful weapon, which is forged when they combine action to further industry, there will be a great extension in the number of chemists retained in our works.

Then the manufacturer will search for the best brains and for those, who have the greatest experience, and will not be content with a small laboratory for testing purposes.

As an alternative to scientific control, the manufacturer must advance on empirical lines. This operation is always slow and uncertain. He must be prepared to see his business becoming less profitable and will probably look to speculation in buying and selling to secure a profit, which the works can no longer supply by legitimate means. In the long run, other manufacturers (possibly working in distant lands) will secure the trade he still holds, which could have been retained had he made use of scientific knowledge.

The chemical manufacturer has three courses open to him. In the first, he may take full advantage of the scientific research carried out in his own works. In the second, he may rely upon finding out the nature of improvements developed elsewhere. A technical examination of the finished products will often help him in this direction. In the third, he must rely upon purely empirical methods, as these are developed in the works by foremen, or works managers.

Staff Arrangements.—Given an efficient staff, a

properly organised system of working will follow. Particulars set out on page 152 indicate the general arrangements of a technical staff which should cover requirements. Communications from, and to the other works departments are made or received by the head chemist.

The responsibilities of the heads of the different departments follow their respective duties.

Each technical department is under the control of a head chemist or engineer, who confers with the general manager and receives his final instructions. On details of routine, or for ordinary work, the heads accept full responsibility, but in all cases where development work is in progress, or alterations are suggested in the plant or process, the final responsibility for action should rest with the general manager.

The respective heads of departments confer with each other on points of detail, or when a programme of extension is in progress, or alterations in plant are contemplated.

Where work is continuous junior members of the respective departments may confer with one another, especially on night duty. A representative of the engineering section should always be in the works to deal with emergency work.

In some cases, night shifts are left entirely to foremen, but there should always be a representative of the process department in the works, who can be referred to should occasion demand. In all cases, a reference to matters of interest which members of the staff encounter is entered in the department's log-book.

Each department sends in a daily report to the general manager. In this way, the manager keeps in close contact with output, the condition of the plant, any experimental work which is in hand, labour conditions, and such other matters as concern the successful working of the factory.

Each member of the staff is made acquainted with his duties by means of a written statement, and a time-table in the department office indicates his hours of duty.

A log is kept in the engineering and process departments, which is entered up at frequent intervals by the engineer, or chemist in charge. Thus an account of what has happened is recorded. This book is initialled by a member of the staff at the end of each shift.

The log-book of one department is not generally open to inspection by members of other departments.

In this way the younger members of the staff learn to be methodical, and are kept in touch with all points so far as they are concerned with the running of the plant. Business habits are acquired, and knowledge of how a process department is conducted is secured.

From these daily reports, the general manager obtains information on all matters connected with the works, and considers those, which require special or collective attention.

Reports and Records.—Such information should form a basis of discussion at a daily, or weekly, meeting, when all important points of works practice are discussed, future developments considered, and all matters of general interest brought up for consideration.

In addition to these meetings, frequent discussions will take place between the general manager and the respective heads of departments on purely departmental matters, which call for examination or decision.

Reports are prepared on any research, which is in hand, or completed. Others, dealing with new constructions, etc., are also made to the general manager's office. The manager also examines and

sanctions all drawings of plant, etc., as these deal with points, which are not ones of routine or repair.

In this way the general manager has an intimate knowledge of all that goes on in the works, and keeps a control on expenditure and procedure.

Also the different departments enter into their duties with a knowledge of requirements, and keep closely in touch with one another, and with the general manager. The head of each department is responsible for all that occurs in the same. In this way, an ordered system of working is set up in the works, and a high efficiency in production is sooner, or later, secured.

It may not be possible in small works to institute such an elaborate system of control. But in every case all steps should be taken to secure efficiency and scientific control. Where the operations are only partly chemical, the staff scheme, as set out, must be correspondingly modified. From the writer's experience, the scheme indicated will meet all conditions of manufacture, where operations are highly technical, and call for scientific control.

In a later chapter, such a staff will be described working out a new process of manufacture, its actual procedure being given in some detail.

The particulars given should enable the student to form some idea as to the actual working conditions in a modern chemical works, especially as these may influence his future work.

CHAPTER XIII

EFFICIENCY AND WORKING CONDITIONS

"He never could leave an accepted formula alone. His mind was like some insatiable corrosive, that ate into all the hidden irregularities and plastered weaknesses of accepted theories, and bit its way through every plausibility of appearance."—H. G. WELLS.

Members of Staff and General Management.—The writer has successfully counteracted a tendency to segregation among the members of the technical staff by holding daily meetings of the heads of each department (and some of the junior members of the same), and making certain that all responsible members shall attend these meetings. This substitution of concerted action for individual effort leads to a speeding up of the application of research, as apart from a more efficient management of general affairs.

Careful minutes are taken at these joint meetings, and these are circulated among the different departments concerned. These, with a carefully thought out agenda, secure a continuity of procedure, and give a record of progress.

Apart from this, the manager will, of course, have many consultations with individual members of the staff on points of detail as apart from general policy, which for convenience will be dealt with in general meeting.

In addition to these daily meetings, it is advisable to hold a monthly meeting of the whole of the technical staff, when progress is dealt with on more general lines.

By the means outlined, satisfactory progress can be achieved, and the many influences at work in a works may be reconciled, and utilised in the most favourable manner.

The Manager of a Chemical Works.—The manager should have a general knowledge of the principles of science, an experience in the working out of new processes, and also a knowledge of engineering affairs.

Such a man may be an engineer-chemist or a chemical engineer, as the case may be. In addition, he must have a knowledge of works practice, be able to manage men, and be capable of working out, and maintaining a system of factory routine which is efficient and scientific.

A manager who is only a chemist, engineer or business man (as this is understood in this country) is apt to make mistakes, from the time when the site may be selected, to the completion of the works, and the running of the plant.

An error in the selection of a site may handicap an industrial undertaking. Such a mistake may only be rectified at prohibitive cost. Attention to such details may make all the difference between success and failure, and the combined experience of all is necessary, if the best result is to be secured.

The young worker, who hopes ultimately to take a hand in determining the policy of a modern undertaking, must prepare himself for such an experience, and be efficient in many ways. He must use his knowledge of chemistry in a general way, and as part of a larger policy.

Research, or a Waiting Policy.—It has been a common practice among British manufacturers to adopt a waiting policy. This policy is based upon the belief that it is safer to let others work out improvements, and discover new products, and then

either by royalty on patents, or at the expiry of the latter, to utilise discovery in this second-hand way.

The leaving of pioneer work to others may result in an immediate saving of money, but in effect this leads to a state of bondage.

The effect of such a policy is deadening. To be continually passed on the road is disheartening. To have to pay toll to those, who are more awake, encourages a state of inertia, which in time will spread through the factory.

Apart from loss of prestige, which must come to those who play the waiting policy, the advantage, which goes with a new method of working, or a new process of manufacture, passes to others.

Many examples might be given to illustrate the disadvantage, which comes with delayed action. One must suffice.

Some years ago, a new dye called Rhodamine was put on the market. It possessed qualities which were up to that time unknown. The cost of this dye was about 35s. a pound, and the world's markets were secured to the inventors by patent rights. When the patent expired, the cost was reduced to somewhere about 5s. a pound, at which it presumably carried an ordinary manufacturing profit.

On a waiting policy the whole of this advantage would be lost. It is therefore obvious that a firm starting at a late period, and making use of research which has been carried out in other works, can only expect to secure ordinary manufacturing profits.

During the time when these large profits were secured, ample opportunity was secured to work out the best conditions of efficiency. Such work is always tedious and often very expensive. At the time of the expiry of the patent rights the original discoverer should be in a position still to secure the larger trade in this material, because of the greater knowledge of manufacturing conditions, which was

gained at a time when profits were so large, that the cost of experimenting could be neglected.

The one system has proved to be sound and rational, and the other inefficient, and in many cases, unworkable. Given proper organisation, the cost of research is trivial as compared with the results obtained. The heart of a works should be found somewhere near its research department.

A general manager, who has had a scientific training, will always appreciate the fact, that, by investing in trained investigators, he is working for the creation of capital, as expressed by acquired knowledge.

How this may work out in practice is instanced by an English concern, which at one time made a yearly profit of some £60,000 per annum by following the ordinary lines of manufacture.

Subsequently, and with the same management, a new process was developed. The profits increased to some £3,000,000 per annum and a capital appreciation from about £300,000 to £30,000,000.

Such cases as this one are not met with every day, but they represent the high-water mark of endeavour, based upon satisfactory conditions of scientific investigation, combined with sound business methods.

Those, who work on scientific lines, do so because they have realised that it pays. They have found that the discovery of a more efficient process, or of a new manufacture, creates capital in a way that no other means can compete with; that when a satisfactory result is obtained and the results capitalised on a basis of ten years' profit, ordinary procedure is reversed and the advantage gained is out of all proportion to the money expended upon experiment. Instead of a dividend earned upon capital, capital is created through expenditure, which is small as compared with the yearly profit arising from the same.

Staff of a Modern Works.—The nature of the arrangements made to secure efficiency in works management and control may best be realised by considering the varying departments concerned in works management and the main lines of communication between them.

The actual arrangements will, of course, vary in different works, but those indicated may be taken as typical of what should exist in a works where advantage is taken of modern methods.

It is obvious that such a staff arrangement will go with a large output, and that the capital involved must be on a sufficiently liberal scale to allow of efficient working. It is doubtful whether full advantage may be taken of scientific control, when such conditions are absent.

This makes it difficult for small works, and no satisfactory method of overcoming it has yet been devised. The difficulties in the collective research, as this may be arranged between a number of small firms, are great, owing to the many conflicting interests involved.

Research in the Works.—A works must be of a considerable size to justify the starting of a department of research and scientific control, as this is now outlined. It is doubtful whether a modern chemical works should have a smaller capital than £200,000. Under such conditions, and with a satisfactory turnover, a works should support without difficulty a technical staff similar to the one to be described.

In the course of a few years the full benefit of such an organisation will be secured. In works, which are mainly kept going by research, chemists may run to hundreds. But such a works is really an industrial research laboratory, to which a full scale manufacturing plant is attached.

That such requirements do not apply to chemical works alone is seen in the statement that one of our largest electrical concerns spends £65,000 per annum on research.

It is impossible to formulate any set conditions, which will apply to all chemical works, but generally the staff arrangements mentioned are equal to the requirements of any modern works. Each case must be carefully considered in the light of its special requirements.

Chemical Department in a Works.—This may consist of the following sections :—

General Chemical Laboratory.
Physical Laboratory.
Research Laboratory (inorganic and organic).
Dark Room.
Technical Laboratory (small-scale production).
Stores.

The above department is, generally, adopted in a works where every advantage is taken of scientific investigation. In some works some of these sections may be combined, where the work entailed is not sufficient to justify their individual existence.

The chemical staff consists of a chief laboratory chemist, assistant chemist, and from three to ten or more assistants, who may be engaged on testing operations or research work, as the case may be.

Works, which owe their existence to research, may employ a larger number of chemists. Examples may be seen in the dye industry, where the chemists may run to several hundreds.

The above scheme covers all the requirements of an organisation suitable for chemical works.

In addition, there is the Process department, which deals with the conditions of manufacture, and sometimes with the erection of plant. Here chemists and

engineers work under the supervision of a process manager, who should be a chemist with considerable works experience.

In a works, where processes are worked continuously, the process chemists will probably work in nine hour shifts. That is to say, these men will be on duty for eight hours, with an overlap of half an hour at each end of this period for an informal talk with the preceding or succeeding men.

In cases where two, or more, process chemists are on duty at the same time one of these is generally regarded as senior to the others, and in charge of the shift.

In some works the process is in charge of foremen, who work under direction of the works manager, or head chemist; but where the process is complicated, or where many products are in course of manufacture, it is thought that the former method is preferable. It may be allowed, however, that this is not the universal opinion of those, who might be expected to form a sound opinion.

Probably the circumstances of actual manufacture must determine this point.

The Starting of a New Process.—The procedure, which might be followed with advantage, is outlined. In this case all the resources of a modern works are brought to bear upon any important problems of immediate importance.

In the case selected the proposed manufacture is concerned with the large scale production of an organic compound, where the desired output is not less than five tons per week. The works is taking up its manufacture in competition with existing concerns, which produce the same articles. The details of manufacture are unknown, but the general reactions involved have been described already in text-books.

Under such conditions the process of development may follow the course now indicated.

The general manager, after consultation with his directors, has already decided that this new product should be manufactured, if the conditions, which make this possible, from a commercial point of view, can be discovered.

The next step taken is to call a meeting of the heads of the main operating sections of the works, so far as these may be concerned in this particular matter. The laboratory chemist, engineer-chemist, and engineer will certainly be present. The proposed manufacture is then brought up for consideration.

All the technical information concerned with this manufacture is placed before the meeting in memorandum form, and careful minutes of the meeting are kept. Further suggestions as regards alternative methods, or of any general criticism are called for and carefully considered.

Following this meeting the laboratory chemist will at once get to work and collect and classify all additional references to the matter in hand, or to similar work, which may be available from private or public sources.

When this information has been digested, a preliminary research will be undertaken on a laboratory scale, in order that direct information may be secured as to the working of the process selected in the first place, and also to obtain additional information on points, which seem to require special attention. The whole process of production is then carried out on a laboratory scale, and so far as this is possible an idea as to its efficiency is obtained.

Laboratory Research and further Development.—Much time is saved at this stage by a consideration of any alternative methods of production, which seem

to offer an advantage over the one originally suggested.

In this direction, it must be remembered that such advantage may be connected with works practice rather than actual reactions.

The possibility of useful by-products being obtained must also be taken into account, especially when these can be utilised in some other process already in operation in the works.

In many cases it is almost impossible, at this stage, to decide which of two processes is the better. Local conditions may greatly influence this decision. The presence of a bad effluent might lead to a process being abandoned.

It repeatedly happens, that a process, which gives satisfactory results in the laboratory, fails on a large scale. Laboratory results obtained at this early stage will therefore be subject to careful re-examination.

Processes, which seem to offer great possibilities in the laboratory, are often turned down for reasons of works practice.

One factor is ever present, or sought for. Every means is taken to secure simple conditions of manufacture.

Immediately it is possible to suggest a likely process of manufacture, it is important that the works staff shall be in a position to offer criticism on the same. A further joint meeting of the staff is therefore held and the different stages of research, as these have been carried out, are carefully considered. The opinions of the process manager, or chemist, and the engineer-chemist are of special interest at this stage.

Relative Efficiency of Processes.—At this stage of development one of the greatest difficulties is to determine which of a number of possible processes

will give the best result in large scale production Much depends upon a proper selection.

In most cases laboratory opinion on this matter will be received with critical attention by the process staff. For many processes, which can be worked in glass or platinum, are not satisfactory when worked in an ordinary chemical plant.

Ultimately, a time is reached when the laboratory has exhausted its power of investigation, and can, for the time being, make no further suggestions. The process staff has also considered the proposed manufacture, and made suggestions, and the engineer can suggest no further modifications in plant construction.

A preliminary design for a small works plant has also been considered and got on the drawing-board. All points in plant construction, or the working of the process which seem to demand most attention, have been carefully examined.

Experimental Plant.—The next step is the erection of a small experimental plant, on which the process can be operated on a small manufacturing scale, possibly producing the final product in 100 lb. lots.

On points of detail, the draughtsman may now offer important suggestions, based upon his past experience.

Materials used in Plant Construction.—The chemist and engineer will work in the closest collaboration, and many tests may have to be made on certain materials, which may, or may not, be suitable for plant construction.

Generally it is a matter of selecting the least acted on material available for the intended purpose. Upon this will depend the life of the plant, a most

important consideration, especially where the plant is expensive and complex in its nature.

This is a good example of the fact that laboratory work is not the beginning and end of research.

If a plant cost £10,000 (which might be considered a reasonable sum for one producing five to ten tons of finished product per week) success may come with one that has a life of from five to ten years, and failure with one that only lasts one year.

The cost of the material produced must cover renewals to plant. Thus, the amount to be added will vary between £10,000 and £1,000 per annum, as the plant lasts one year or ten.

A charge of £10,000 would amount to £50 per ton in the former case, and only £5 in the latter.

The former would probably be prohibitive. The value of past experience, which can produce a plant lasting ten years instead of one, is too evident for discussion. Works experience alone can, in the majority of cases, enable a plant to be designed that will approach the latter figure.

Results obtained on Small Manufacturing Plant.— As a result of a two or three months' run on the experimental plant, data will be obtained enabling an estimate to be prepared covering the yield, and results which should be obtained on the final and large plant. Its minimum should be determined with a safe degree of accuracy.

By a careful examination of the plant an estimate may also be obtained as to its probable life. If the estimate obtained is unsatisfactory, the process may be discarded, or else further improvements sought to overcome the specific difficulties observed. If necessary, these can be tested on the same plant before proceeding to the erection of the final one.

During the time of working care will be taken to check efficiency at each stage. In this way

inefficiency can be discovered, and special means taken to improve those sections of the plant.

All available information must be collected as to actual running conditions. The plant must be operated with the same care as if it were a full scale one. The operations must be followed in every detail, for it is much easier to make alterations at this stage than on the large plant.

Any additional observations, which suggest that further improvements can be made in plant construction or working conditions, must be again considered when designs are prepared for the final plant.

Large Scale Operations.—A time will arrive when it is considered that no further advantage can be secured by delaying the selection of the large plant, and its erection.

The flow-sheet covering the processes involved in manufacture will be revised, and checked by the results obtained on the experimental plant.

The information now available is based upon actual experience. It will relate to the practical working of the process, and plant, and suitability of the materials utilised in plant construction. A provisional estimate of the life of the plant will also be secured.

On this information, the final designs of the plant will be decided upon, and plans prepared in the drawing office. These are considered by all the members of the technical staff who are interested in large scale production.

During the actual erection of the plant, further research will be put in hand. By this means, time is saved, and doubtful points dealt with.

The experimental plant should be kept working up to the time when the large plant is in active operation. It may then be used for any further experimental work.

The size of the plant unit requires special consideration. The partial breaking down of one section of the process will correspondingly hold up the whole plant. This must be guarded against, therefore the unit of actual working should not be too large in its relation to the output of the section it belongs to.

It is inadvisable to reduce the number of units in any section below four. Even then output may be reduced by 25 per cent. when a single unit breaks down. A better plan is to work with three units, and have one in reserve.

Manufacturing Results.—The three, or six, months' cost sheet for the experimental plant will indicate how far the original estimates are confirmed on a works scale, and how far works efficiency agrees with laboratory estimates.

A careful examination of the cost sheet indicates to the practical chemist, or engineer, in what direction further improvements are required. The properly prepared cost sheet is an important aid to progress. It points out the most expensive section of the plant, where efficiency is lowest, and to what extent (in theory) it is possible to improve things by further investigation.

This brief description of the way the writer would attack the problem of large scale production must suffice. This method has given good results in the past and it may be considered to be a satisfactory one for general use. It is not suggested that it is the only course to follow, but it is a method which has brought success where it has been applied.

It is important that all the respective branches of works activity should be interested when a new process is being considered. In this way, every department will be concerned with success or failure. In the latter case, valuable lessons may be learned for the future.

It will be seen that there are many important points, which require consideration during the period of small-scale production.

Among these may be mentioned the following :—

(1) Cost of production, as a direct measure of efficiency.
(2) Life of the plant selected.
(3) Labour requirements, skilled and unskilled.
(4) Suitable plant construction.
(5) Satisfactory supply of raw materials, at a cheap rate.
(6) Data concerning actual running experience, as this can be obtained from the running of the small plant.
(7) Utilisation, or disposal, of by-products.

In almost every case, there will be other considerations connected with the special operations involved in manufacture. These must be carefully looked for, and must receive close attention and investigation.

Once more, the chemist's work never ends in the laboratory, but only commences there. Laboratory work, by itself, will never advance industry under modern conditions. It is only the initial stage in development, and that very often is the easiest of all the stages of research and investigation, because many factors which make research difficult in the works are absent.

Conditions vary with Scale of Operation.—It is obviously difficult for some to realise that there is an extraordinary difference between laboratory and works experience, and that the former may often be valueless in itself.

When substances are prepared on a scale many thousands of times greater than that ever attempted in the laboratory, the conditions of production change. These have to be modified in proportion to the scale of operations, until at last a point is

reached where mechanical or other difficulties prevent a further extension in scale production.

In some cases, the economic limit to working is reached before the physical one makes itself a controlling factor. In others the reverse is the case.

CHAPTER XIV

LARGE-SCALE OPERATIONS

"The thinker wills, the dreamer is a passive instrument."
VICTOR HUGO.

Works Practice.—Although it is impossible to consider all the conditions, which govern works practice, yet a simple case will be taken, so that the nature of the control and the requirements of large scale working can be indicated.

The case selected is the manufacture of synthetic phenol from benzene, the well-known "lime process" being chosen. It will be remembered, that when using this method benzene is first sulphonated, the benzene sulphonic acid produced converted into its calcium salt, and this into the corresponding sodium salt. This salt is then fused with caustic soda, the melt containing sodium phenate dissolved in water leaving sodium sulphite insoluble, and phenol set free by adding sulphuric acid in excess. A final distillation of the separated layer of phenol produced completes the process of manufacture.

On a large scale many problems present themselves, and demand close attention before a satisfactory yield can be obtained.

The conditions of manufacture in the works call for important modifications in procedure from those of the laboratory. Upon the setting up of these will depend the successful working of the process.

The question of the by-products produced and their special treatment, as this is required to prevent a loss of the products of the main reaction, calls for special inquiry.

The matter of the size and kind of vessel require in the different stages of manufacture is a deter mining one. The nature of the material used fo these vessels, as they may hold acid, alkali, o special solutions, requires attention. The design o the vessels may also influence efficiency, often i quite unexpected ways.

In starting a process of this nature, it is advisabl to prepare a so-called flow-sheet. This indicate to the experienced worker the nature of the plan required and the relative volumes of the solids o liquids at each stage of manufacture. According t the temperature of reaction in the different opera tions involved, so the design of the plant must vary Vacuum or ordinary distillation may be required The time of each operation must be determined.

All such details will have their influence on plan design and working conditions. The number o working units in each section of the plant must b decided from a point of convenience. In a badl designed plant, it may be found that when actua working commences one, or more, sections of th plant are inadequate for the producing capacity o the others. Nothing is more annoying than thi and much time may be expended in correcting sucl an error.

Design of Plant.—In many cases it is impossibl to design a plant from the data obtained in th laboratory. Processes work so - differently on a large scale. Where a process may be completed i a few minutes in the laboratory, it may take hour or days in the works.

Setting out the Process.—When the final flow sheet is examined it will be seen that it present a clear picture of the requirements of works practice By calculation, the different sizes of vessels can b determined ; the volumes of solutions to be deal

with can be estimated. From this flow-sheet the lay-out of the plant can be settled. The question as to whether one or more buildings should be used, and how the process can be best divided up, so that a check upon production and efficiency at each stage of manufacture can be accurately determined, must be considered. The last point is very important. Without some such provisions no check can be kept upon the efficiency of the process of manufacture, and no steps can be taken to improve this section by section.

A reference to the flow-sheet indicates in a definite manner the possible sources of direct loss. It will be observed that at certain stages of manufacture liquors are run off, and waste materials, like calcium sulphate or sodium sulphate, are thrown out of the system.

Waste liquors and insoluble precipitates must receive special attention, in order that no undue escape of other, and more valuable, products may occur.

For instance, the washed sodium sulphite, as it is sent to the tip-heap may contain 10 per cent. of sodium phenate, if it is badly washed, and 0·1 per cent., if it is in a satisfactory condition. Of course, experience and research is necessary before the latter figure can be obtained, or even approached.

The calcium sulphate sludge from the filter press may contain 10 per cent. of calcium benzene sulphonate, or it may, under the best conditions, contain about 0·2 per cent. A great loss of phenol may occur in the waste liquor from the vessel where the phenol is "split off" by acid if not carefully watched.

All such points, and many others, determine collectively whether the efficiency of production is 40 per cent. on the one hand or 90 on the other. That is to say, the process can either be worked or

not, according to the attention which is paid to all the points involved in manufacture. Such points cannot be followed up except on chemical lines in the works, based upon a constant succession of analyses of the different intermediate products in the stage of manufacture.

The labour expended upon such control can only be efficiently applied when production is carried out on a large scale.

Such a control could not be easily applied to the product of, say, one ton per week, but it can be when this is 30 tons. This is the secret of large-scale production.

The student will also realise that in a works there are certain standing charges, which cannot be reduced. When these are spread over a large production, there is a material reduction in the over-all cost of production. When the laboratory chemist passes to the works and sees masses of precipitate being washed as easily as he washes 10 grammes in the laboratory, the difference in procedure will at once become evident.

The mechanical means required to secure such a result are often complex. Success may depend upon certain small points in procedure, which he will fail to discover for himself, even if he watches operations for days at a time.

Size and Nature of Plant.—From the flow-sheet the student may try to set out a factory to produce, say, 100 tons of phenol per week. He will at once discover that this is a complicated operation. What boiler capacity will be required to raise steam for the purpose? Must the steam be superheated or not? What method of heating the fusion pots should be adopted so that a control may be obtained within a few degrees at a temperature exceeding 300° C.?

How are the varying solutions and solids to be

passed from one reaction vessel to the other? What kind of pumps will be required for this operation? Numbers of such problems will present themselves, and each one, in its way, is important and may influence efficiency of production either from a labour or material point of view.

All such points must be settled by the engineer-chemist. However carefully things may be thought out it will always be found that fresh problems present themselves during the period of actual working. The chemist's work never ends. There are always fresh problems to face—always fresh ideas to test on a manufacturing scale.

How many students leaving a college have any idea how they should proceed in setting up a plant of the nature indicated? And yet the case selected is one of the simplest that could be chosen for illustration purposes. If the students were asked in examination to set out the conditions for an annual production of 1,000 tons of phenol on a basis of an 85 per cent. efficiency on theory, how many of them would have any idea how to proceed? Yet this is the kind of problem, which often occurs in a large works manufacturing organic products.

Works Problems.—All students entering a works should have some idea as to the problems they will have to face, and work out. There is no reason at all why the students in a chemical department should not have experience in such matters. Were they to work in conjunction with mechanical and electrical students the experience would have a greater value still.

No better training could be provided than that the students should engage upon the preparation of a lay-out of a factory, and a consideration of the plant required for the manufacture of a recognised product, such as the one indicated.

If, in addition, they have a class knowledge of the underlying principles of research, they will be able to take their place in the works and become useful members of the staff in a shorter period.

Record of Progress on the Plant.—There are many ways of keeping a strict record of the working of a plant. The working of each unit should be recorded hourly by the chemist in charge. In the respective columns devoted to each operation or section of the plant a straight line may indicate that the same is out of operation, a crooked line that it is producing. Where the line is straight a note is entered as to the cause of the delay in operations. A blank indicates that the section referred to is under repair or not in use for the time being. This diagram is placed in an observation office centrally placed, and at any time the chart may be consulted and an immediate idea obtained as to the hourly working of the plant as a whole, and sectionally.

Such a record is a necessary part of efficient control, although it is often absent; the daily sheets are filed for future record and in themselves supply an accurate and useful account of the progress of manufacture and the working of the plant.

From these a weekly report may be drawn up with certainty, and this, with a weekly stock-taking of raw materials, materials in process (calculated back to raw materials on the known efficiency of each section of the plant), and an account of output, will give a fair idea as to the working of the plant from week to week.

Where the cost of production is also required, this, too, may be calculated from the above data, cost of repairs and renewals being allocated to the same upon a basis, which will vary with the nature of the work, and also with the special ideas of the manager, or process chemist.

The costing department, which prepares such details, is a most important aid to correct and proper working, and is always present, and fully utilised, in a modern works.

In every case, scientific control pays for itself over and over again.

The Chemist and Process Labour.—The process chemist acts as a link between the management and labour. In dealing with the actual manufacturing operations he will come into close contact with the process hands, who carry out such manual operations on the plant as are necessary to its working.

The efficient handling of men is a matter of prime importance. In the first place, the men must have confidence in the leadership of the works or shift chemist, and they must be treated with tact and consideration. At the same time a system of discipline must be set up, as this is necessary to efficient running.

In the development of new processes, or the running of old ones, much depends upon the class of workmen employed on the plant. Where they take an intelligent interest in things, the work of the process chemist is far less laborious. The skill of the workman is of course primarily dependent upon his education and the kind of instruction he has received from those who direct his operations. The process chemist, where he directs labour, must be able to impart his instructions to the workmen in an intelligible manner.

To a great extent, the suitability of the conditions of actual working is largely in the hands of the process chemist.

In a modern chemical works, the workmen, who understand their duties and realise the actual part played by those concerned with routine work, and the added value of the work of those engaged in the

further development of industry, are the ones, who are most useful.

The workmen must be made to realise that they must, from a want of knowledge of the many difficult problems concerned with works procedure, act under instructions of those who have such specialised knowledge. There is a distinct call for a better understanding on this point.

The way labour is utilised must also be understood by all those who direct operations. Co-operation in labour is known as simple, or complex. In the former case a number of men help each other in the same employment. In the latter case they aid each other in different employments. Thus one may make cloth, the other grow wheat. One may direct, the others carry out instructions.

In most chemical works, certain men are required to carry out certain operations and to follow instructions in an ordered sequence. Their work will, therefore, be valuable when the instructions issued are satisfactory in their nature, and when they are followed intelligently.

Much of the work of the process chemist is taken up in controlling manufacture by directing labour. The workman has, in the majority of cases, completed his work when he has carried out instructions in their proper order, and at the proper time.

The advance, which has taken place in our knowledge, as this has been obtained by research, has placed such a gap between those who direct and those who carry out operations, that the latter have not the knowledge to understand the underlying principles involved.

Labour and Improvements on the Plant.—After working for some time on a process, an intelligent workman will often offer suggestions concerning improvements in detail. These are generally

empirical, but they are often of value, the more so when one remembers that they have originated owing to intimate connection with the plant itself.

In dealing with labour, the process chemist or manager must rely upon a sympathetic understanding between the workmen and himself, and the workman must be brought to see by actual experience that the process chemist is fully able to carry out the operations, and that he is not asking the men to do something that he cannot do himself.

The great thing is to so carry out control, and manufacture, that the workman is brought to an understanding that control must rest with those, who use their brains rather than their hands.

On the other hand, he must equally understand that a great deal depends upon the way he works: that by careful attention he may help to keep the plant in better running order, and increase its life by so doing.

When this spirit is fostered, the monotony of routine work is greatly reduced.

Although such matters as these belong to the works, the student will do well to remember that any information he can obtain on such matters will be all to the good, and make his subsequent period of probation in the works a shorter one. When he actually enters upon his duties in the works, as a process chemist, and he finds that he is gaining the confidence of those he directs, he may rest assured that he is travelling on the right road and that he possesses the power of sympathy, as well as control.

A sign of inefficiency at some stage of manufacture often indicates a want of sympathy between the workmen and the process chemist. The undue presence of industrial fatigue is also a sign of inefficiency in control, or of a badly designed plant.

Advance often comes from working back to the cause of some defective condition in manufacture,

and altering existing conditions so that they more readily comply with efficient working.

Thus the skill of the workman must often be dependent upon the knowledge possessed by the process chemist. Mill pointed out that the number of persons fitted to direct and superintend any individual enterprise, or even to execute any process, which cannot be reduced almost to an affair of memory, or routine, is always short of the demand; that to this is due the difference between the salaries paid to such persons and the wages of ordinary labour.

Although this difference has been greatly reduced by the recent advances in the rate of wages paid as compared to any advance in salaries, yet the same principle holds in the majority of cases. The chemist must therefore realise that his superior position is entirely due to his greater knowledge, and that he must do all he can to apply this to some useful end.

Labour's Position in the Works.—To sum up, the scientific investigator is mainly occupied with operations which have not been established, or previously suspected. Ordinary labour is concerned with the carrying out of operations, which have been regularised by experience and set out in such a manner that a knowledge of their true meaning is not necessary for this successful operation. The reason why the operations are carried out, or their true nature, may be hidden. No skill beyond that of common sense is necessary. Skilled workers in the factory work on empirical lines, and act under instructions, or at the dictates of their own previous experience.

The scientific worker, by a mental process, invents new methods, or means of action. These, in their turn, are followed up and operated mechanically by the workers.

Science being a branch of industry, practical

research is a type of pioneer and highly skilled labour, where thought and action are relatively complex and sustained. In time the results are incorporated in works practice, becoming routine work for those who operate the actual processes or aid in production on a large scale.

The relative value of the brain and normal workers in industry is under constant discussion. A concrete case is that of an investigator who, by thought and knowledge, discovers a new steel which may double the output of the lathe. By such an innovation, the labours of a hundred thousand mechanics may be made twice as productive. That such labour should be classed with that of an entirely routine worker is beside the mark. Generally, the former influences, from the time of the discovery, the output of others. Manual labour only influences, or modifies, the action of the individual himself.

CHAPTER XV

THE STUDENT AND HIS COURSE OF TRAINING

"The vivid and creative mind, by virtue of its qualities, is a spasmodic and adventurous mind. It resents blinkers and the mere implication that it can be driven in harness to the unexpected."—H. G. Wells.

The Student's Position.—The combination of knowledge and experience is the essence of scientific endeavour. The course of instruction should therefore follow a system, which leads directly from the college to the works without a break. The course of instruction is a part of the life history of the working chemist, and not a thing apart.

In the development of an efficient system of instruction great strides have been made in this country since the "eighties," but further changes become imperative as recognition comes of the fact that the college must fall into line with general practice, and that the training required by the student shall be of a more general nature, and not confined to laboratory practice, and the theory (for the time being) which is supposed to describe the actual working of natural processes.

In the practical course of chemical training, which will completely meet the requirements of students, who are to engage in chemical industry or investigation, certain very definite conditions are essential.

First, and foremost, a knowledge of the framework, upon which all research is raised, should be imparted to the student at an early stage. The principles enumerated in this small volume, and possibly a

good deal more, should be known to all students. Otherwise their training will be superficial, and not based upon the actual principles of research, which underlie these. The student should not be left to gather these particulars for himself. They should be imparted to him at the beginning of his course of instruction, and he should be impressed with the importance of having a satisfactory knowledge of the basis of the whole fabric, upon which he will work and has his scientific being.

The student generally starts practical work with a fair knowledge of theory and experiment. Both may be out of date before he is very much older, but the principles underlying all this work and experience will last. He will realise that the things which matter are concerned with the framework; that all the rest is merely a temporary, if progressive, filling, which persists and must persist until some other experience, greater than observation and experiment, takes its place.

The knowledge of the why and wherefore of research will always serve and carry the student into the works with a correct idea of investigation, one which will enable him to immediately enter into his work without the delay caused by a more or less complete readjustment of his ideas.

It is necessary for the student, in the latter part of his instructions, to have personal knowledge, and this is gained by direct contact with the actual operations of research, or original investigation.

Knowledge as set out in the average text or reference books does not pretend to convey the impressions which are essential to a correct training. Routine work in the laboratory, where student after student repeats the same task, does not engender the right spirit of research. It produces the kind of trained investigator, on whom H. G. Wells pours such scorn and who is seen in the works, helpless

and hopeless in any sustained effort, or serious work where anything more than routine is required.

In many cases, the student's time is taken up with study of detail where he should be dealing with principles. The difference in the mental training in these two cases is fundamental. The one is basic, the other ephemeral. When he does not study the principles of the framework and the deeper and wider philosophy of his work, his training is necessarily incomplete. Its presence keeps knowledge fresh; gives an idea of its true value; leads onwards.

On the method of imparting knowledge of the *principles* of research and the technique of the same there is some disagreement. Based upon a somewhat wide experience in works practice, the writer came to the conclusion that this can be best achieved by the teaching of the principles of research in class. Individual research alone is, in many cases, likely to lead to a restricted idea of values where a student follows the example of one man.

Physically, too, it is impossible for every student to have the advantage of a close companionship with an experienced investigator, let alone a great thinker.

Again, in practice, it has been observed that this latter process does not always give satisfactory results. Students do not somehow gain the object of their training by such means, as they should in a more organised course of instruction, unless they are in the closest touch with an original worker.

System of Instruction in Research.—It therefore seems that the only sound method is that the original research carried on in a chemical department should be open to the personal inspection of all the students of the department at some stage of their training, and that they should have the opportunity of following this to the best of their ability.

Such a process brings the chemical department in line with the medical department (so far as practical research is concerned). It is submitted also that this should be one of the main branches of college training.

As a secondary measure, the students, in groups, should repeat some classic (and easy) examples of research in all their detail.

Just as training is imparted (in the general laboratory) in the ordinary methods of analysis, so instruction should follow (in the research laboratory) in the methods which make up and control research. This course seems so essential that it is again put forward as a definite aim.

Future Developments in Instruction.—When the history of the last thirty years is written, great stress will undoubtedly be laid upon the rise of the Heuristic method of instruction, and the name of Professor H. E. Armstrong will ever be closely connected with this important development, which has certainly made the college course a more practical one.

The next step to be taken will be (in the writer's opinion) the further one of combining all chemical experience and selecting a college course of instruction based upon this wider knowledge. This should be set out by the workers in both the college and the economic world.

This should not take the shape of an extension in the so-called technical course, but should follow the course of a wider and more satisfactory general course, which will make provision for the points mentioned.

Professor Armstrong's advice, "Young man, think for yourself," is admirable. In the larger course, it will be relative to the student obtaining a satisfactory training and instruction, in the controlling principles, as these must discipline his thoughts.

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It is held, therefore, that the path of future ogress is best indicated by a careful consideration the requirements of the practical man; that, :hough a great step was taken when the Heuristic ethod was put into practice, a further step is cessary before the training of students can be nsidered to be satisfactory. This step calls for e considered opinion of all those, who are engaged practical work, and the co-ordination of the whole tivities of chemistry. As knowledge of the things industry advances, it must be altered to meet :ered conditions, and correspondingly improved. ıe student must feel that, although he is taking ırt in a sectional activity, this is thoroughly up to .te; not up to date in one direction only and :omplete in others.

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Scheme of Training.—A scheme similar to that dicated would naturally include a knowledge of

power requirements, steam consumption, water supply, disposal of waste products, the selection of suitable materials for plant construction, and a host of other problems which may influence efficiency. A knowledge of text-book chemistry is but a small point in this development. It is by the things which are not in text-books that efficiency is brought about in the works. Only actual practice in the methods of realising what these points are can sustain such a training. The college, which neglects this larger side of chemical experience, does not give a satisfactory training to the student who intends to enter a chemical works and does not intend to confine his attention to laboratory work. It must not be imagined that the practical side of works practice can be imagined within the college walls, for then it will take the form of a practice, which is based upon the one-sided laboratory experience, and leave out of consideration the wider and more direct methods of production on a large scale, which, after all, is the main object of chemistry and the only practical mainstay it possesses.

Information Required in Works Practice.—As industrial science becomes more complex and working conditions more difficult, the training necessary for those who are to engage in such work will change correspondingly.

Many subjects, which are not yet brought into the practical course, will have to be considered. Beyond everything the worker should gain some experience or knowledge of works conditions while his mind is in a receptive state.

This knowledge cannot be gained in the laboratory. The more general part of a chemist's experience can only be met with in large-scale production. But a good idea of its nature can be learned during the student stage.

If there were no application, knowledge would be sterile. It is mainly useful as a guide to practice.

From this standpoint, it is the more essential that those, who teach in our colleges, should have a personal knowledge of the nature of practical work, and that they should realise that even if academic knowledge is ultimately found to be valueless as an expression of actual fact, that it may be of considerable interest and value to the practical worker.

The absence of an efficient co-operation between the works and the college has led to many misunderstandings both in practice and training. Just as it is impossible for a man to realise the nature of another's work unless he inquire into its details, and understands its aims and objects, so the demonstrator in a college must lack a proper sense of works experience unless he inquires into it, and tries to understand the different attitude adopted by the practical worker from that of the academic one. It is necessary for the college worker to understand the point that there is a distinct difference between works and college practice, that the latter is not *necessarily* of value in the works.

Period of Instruction and Training.—This matter has given rise to a good deal of discussion, and will continue to do so until the different sections of activity are so co-ordinated that it matters little how time is divided.

Generally it is agreed that the college course should not be less than four years. When such a course is followed it is evident that a maximum of experience and knowledge should be acquired, and it would seem that the student should have plenty of time during this period to obtain a clear insight into principles, if not detail. The Institute of Chemistry accepts this period as a satisfactory one

when considering the qualifications of those it examines, with the reservation, that, in addition, a further three years should be spent in actual practice before the Fellowship is granted. In this direction it has done good service. Its insistence on a code of professional conduct is also sound.

A Student's Holiday.—The student should undoubtedly gain some experience of works practice during the receptive years of his life.

The college vacation is considered necessary as a rest period, *so far as college experience is concerned.* The three months' summer vacation is probably a correct provision under existing conditions both for student and teacher.

Part of this period may with great advantage be spent in a works. The writer definitely promises any student, who will follow this course, that he will gain a distinct advantage.

It will introduce him to actual practice. Let him take service as a process man if need be. Thus he will gain experience in the ways of the workers he must ultimately control and direct.

Post-Graduate Work.—In certain quarters it is held that students should enter upon a post-graduate course of research at the college. It is doubtful whether this course is a good one for the chemist, except in cases where he confines his attention to laboratory work. In this case the further contact with research conditions, as these are carried out on academic lines, may prove useful in some cases, in others not.

The period between the ages of seventeen and twenty-three is a critical one. During this time the chemist's future will probably be settled.

His brain is particularly receptive to outside influence, and it is as well that he should gain an insight into the conditions of practical working

during the period. This can be achieved if he enters the works during the vacation.

Later on, ideas have become stereotyped and have a way of persisting through life. The absence of an early practical experience, in many cases, interferes with the more practical side of work and restricts development.

On the one hand the student must gain knowledge, and on the other experience. Many fail to secure the full benefit of both. Far too much stress has been laid upon the matter of examinations.

Preparing for these is an aid to knowledge, but not experience. There is a Plimsoll line in training, as there is in navigation. It is as dangerous to overload a mind with detail, just as to overload a vessel with cargo.

The extraordinary importance of a practical training therefore is seen, and the responsibility, which rests upon those who determine the course of instruction, cannot be over-estimated.

The very efficiency of a training in chemistry may disguise the fact that it might be very much more useful to the student if it were more embracing in its aims and more practical. The last term is used in its general sense rather than in that, which it is used in the laboratory.

Work in the laboratory is only practical so far as laboratory work is concerned. There is a wider side of chemistry, which brings with it a greater recognition in the industrial world. It is for this that the student should be trained and prepared.

The College Staff.—It is always interesting to examine a college training, which prepares a man for an industrial experience. This should guard on the one hand, against a merely technical training in things as they are, and on the other, should impart an insight into the methods, which must be adopted

when an attempt is made to apply such knowledge in the works.

Just as a merely technical training will leave the worker high and dry at some important stage in his career, so a too theoretical one will prevent his reaching this stage of useful application.

It may be agreed that such a training might lengthen the college course. This is not material if the training is really efficient in its method. Any system, which does not comply with this requirement, should be substituted by one that does. There is only one standard for a teaching course in practical science as it applies to the ordinary student, and that is its efficiency as a link in industrial progress. On any other basis it clogs the wheels of progress. This should be remembered by those who remain in the college to teach succeeding generations of students.

Such men should do all they can to understand and keep in touch with the requirements of the life they are barred from following by their decision to continue in the college. Otherwise they will soon become stale and out of touch with real conditions. And their students, in their turn, will have to gain their experience after leaving the college.

This is a shortcoming, which should be minimised. It would be better for the teacher to spend two years as an interregnum in the works and thus break the continuity of his college life. Even then, if he does not keep closely in contact with industrial affairs, he will soon lose touch with working conditions.

As soon as research becomes old fashioned it must be replaced by more efficient methods of working, and very often changes in organisation, which in their turn will set up a system of new ideas and methods. These are not published to the world for obvious reasons. Yet somehow they must be realised in the college, and allowed for in the general course of training.

At stated intervals, the members of the staff in American Universities obtain a period of leave during which they travel to European centres of learning, and thus keep their minds fresh, by observing the progress made in other directions. If this is not possible in this country the members of the staff should each keep closely in touch with some particular industry, and wherever possible visit the works connected with the same, thus keeping in touch with progress as it is represented in the same.

The Student's Aims.—The late Sir William Osler always gave his first year medical students advice, which was of so practical a nature that it may be repeated here :—

"The master word is work. Throw away in the first place all ambition beyond that of doing a day's work well.

"Take no thought for the morrow. Live neither in the past nor the future, but let each day's work absorb your entire energy.

"The value of experience is not in seeing much, but in seeing wisely.

"The secret of successful working lies in the systematic arrangement of what you have to do, and in the methodical performance of it.

"Do not get too deeply absorbed to the exclusion of all outside interests. No matter what it is, have an outside hobby."

During his early period of training, a chemist will do well to take up some hobby, like photography; one that will relax his thoughts, and yet bring valuable experience and knowledge of general things. The camera, especially if it is used in conjunction with the microscope, is especially valuable. Its use calls for decision, and calculation of somewhat unknown conditions. An almost immediate confirma-

tion is obtained as to the accuracy of the student's decisions.

Every chemical student should be a capable photographer. It is impossible that this will not at some time prove advantageous.

CHAPTER XVI

HE GENERAL RECORDING OF RESULTS AND OTHER MATTERS

"I know not what the world may think of my labours, but to yself I seem to have been only like a boy playing on the sea-ore, and diverting himself in now and then finding a smoother ebble or a prettier shell than ordinary, while the great ocean of uth lay all undiscovered before me."—NEWTON.

The field of experimental research is ever widening; ach discovery is but a stepping-stone to others. ingle observations may (as in the past) give rise to ew sciences, called into existence by new facts or nowledge. There is no finality to research.

The great ocean of truth as truly lies undiscovered s in the day of Newton. It may always remain nfathomable, and refuse to be defined in our system f thought.

The natural development in the field of investiga-ion is of particular importance to the student. The increased tendency to subdivision and the ividing up of science into a number of more or less water-tight compartments (for which there is bviously no counterpart in Nature), is a defect, which it is impossible to ignore. Comparison of the results arrived at in one section with those obtained n another will hardly fail to indicate new lines for nvestigation and widen knowledge. The young nvestigator should pay special attention to this point. Knowledge is extended in this way.

The application of the latest developments in colloidal chemistry to the theory and practice of dyeing, brewing, filtration, and the study of

solutions and their properties, are examples of this work.

The student need only remember the importance of this application to the manufacture of photographic emulsions to appreciate this point.

In the different branches of physical chemistry this inter-dependence is specially called for.

The student, anxious to realise the inwardness of things rather than to act as a mere recorder of diverse phenomena, in terms of certain set methods of expression, will recognise this, and by choosing such a subject for investigation may set out with reasonable promise of success.

Use of Mathematics.—Research which involves a mathematical treatment is a source of inspiration to many, if it be a trial to others. The conditions of research have been so modified of late years that it is almost impossible for the investigator to carry it on in a satisfactory manner without a working knowledge of mathematics. This has not been sufficiently recognised in the past. The methods of teaching this subject also have often been so academic that the student has failed to appreciate the importance of its practical utility.

The far-reaching effect of the application of mathematics to experimental sciences is seen on all sides. It is impossible to consider certain branches of chemistry without it. Its extended use in the science of engineering, or in physics, will be a constant reminder to the chemist of its practical value when its use is kept within reasonable bounds.

The statement has been generally made that from his method of thought the chemist can never be a transcendental mathematician. This may or may not be so, but the general investigator has no such need. He may be content with a sufficient working knowledge of the practical side of this secondary

science. The worker who has not this knowledge may be referred in the first instance to a "Course of Practical Mathematics," by Saxelby, or to "Higher Mathematics for Chemical Students," by Partington. Either of these will indicate that the subject may be treated in a manner, which brings it within the grasp of any chemist, and also one cannot fail to gain advantage from a working knowledge of this subject.

A certain want of understanding between the workers in chemistry and physics has been traced to the fact that in the absence of a common use of mathematics, different methods for expressing results are employed.

The mathematical expression of laws, or generalisations are, as a rule, simple in proportion to their usefulness. A simple arithmetical expression is generally basic; a complicated formula, empirical, and only useful for working purposes when conditions are fairly constant.

Experience indicates that the simpler a generalisation the more likely is it to be a true one. An arithmetical property, which depends upon a simple ratio, is far more likely to survive than one which is obscure in some of its factors. Such a law may be expected to vary with every change in condition, and to only apply over a narrow range of experience. It is empirical, not relative. In ways it is equivalent to a process in industry, where results can only be repeated with any certainty so long as certain unknown or empirical conditions remain constant.

In pure science, mathematics plays a very important part. It is absolutely essential to our methods of research. It bridges chasms, which thought alone could never pass, and pushes research into regions where expressions must otherwise be purely empirical or conjectural. Subsequent experiment has often confirmed results anticipated by mathematical means.

As a means of collecting data and arranging this in terms of general expression, mathematics holds the field in undisputed fashion.

It has been pointed out, that many set a low value on the usefulness of mathematical knowledge, because it is not realised that the mathematician rarely, or never, reveals the secret whereby he discovers the method by which he obtains the result; that while the problem is always solved by analysis, yet, in its final expression, the result is expressed by deduction. Also, that while deductive reasoning seemingly appears to form the essence of mathematical expression, it is a mistake to imagine that the actual work of the mathematician is of a deductive character.

When this important point is not realised, it would seem that the work of the mathematician is simple, each step following directly from the previous one, so that the process seems to demand no real intellectual effort.

Discovery obtained by mathematics is implied in previous knowledge, since it is logically deducible from the same. An exercise of judgment, as in experimenting, is not called for. The degree of evidence cannot be altered in mathematics, or qualified in any way. It is, therefore, obvious that only where such results can be compared with those obtained by direct measurement that there can be any certainty as to the results obtained. At the same time, a good deal of skill is required in the selection of the premises so that unperceived, or unthought-of, results may be achieved.

Mathematics sometimes confirm results obtained by the practical worker in a satisfactory manner. Thus it has recently been shown by R. Becker that when the theory of detonation is developed mathematically the results are of the same order as for "detonation temperature" and pressure produced as those observed experimentally.

Methods of Recording Results.—Great importance hould be attached to the registration of all details f past work. Nothing is more annoying than he search for information the reference to which as been mislaid. This record should cover as xtensive a field as possible, on both the theoretical nd practical sides. All such references must be lassified, preferably by card index, rather than y note-book, so that they may be kept in a con-enient form for future reference. In a few years his source of information becomes one of considerable alue. A note-book for immediate use, and such a ystem of registration as some form of alphabetically rranged record or card index, are aids to systematic ivestigation.

All observations, and any provisional conclusions ased upon them, should be immediately registered. t stated intervals, the progress of the investigations must be closely examined, notes written up, and the ifluence of any further results obtained on the irection of the research carefully thought over, and ny possible developments arising out of them noted. n the long run this saves much time and secures a atisfactory record of results. This is a matter of nportance, and a necessary condition to systematic ork.

It is interesting to note that Faraday, who is ecognised as probably the most precise investigator f the nineteenth century, had (according to Tyndall) sense of order which "ran like a luminous beam rough all the transactions of life." His notes ere found to be numbered, the last paragraph being egistered as No. 16,041.

Publication of Results.—This subject raises con-iderations of great moment to the investigator. Vhen research work is conducted to a successful ssue in a college or university, it is nearly always

published. In other cases publication may defeat the whole object of the research unless, at the same time, protection by patent is obtained.

Publication may take place through the medium of the recognised societies, in which case the communication is submitted to the secretary for consideration by the Publication Committee. One obvious advantage of this method is that the communication may be read before the members and discussed.

The third method of direct publication is in the form of a monograph, treatise, book, or pamphlet. This is the method least often adopted in this country owing to the question of personal expense and distribution.

Effect of Publication.—In pure research, which remains static, the only way of obtaining any advantage is by publication. The only advantage which such work can bring is in its application.

The assumed disadvantage of the non-publication of technical research is not so great as might be expected. The protection which goes with this is only just. It is the equivalent of that given under patent law to those who are willing to publish their discoveries in return for a period of monopoly.

In many cases such a procedure is unwise. In some cases the publication of results by patent set others working on similar lines. Protection is rightly sought in some cases by secret working instead of by patent.

No manufacturer can be expected to give to the world the advantages he has secured by superior enterprise and investigation. Secret working leads to progress. No firm can afford to let others have a monopoly of the advantages which come by research. They must experiment. In the long run such information as may be gained leaks out or is duplicated in other works.

The chemist will therefore see why it is so impossible for firms to allow the publication of results, which have been secured for private ends.

It is surprising how long such an advantage secured by scientific investigation can be preserved, and to what an extent secret working will secure an advantage.

Protection by Patent.—Closely connected with the question of publication is that of protection by letters patent. This only applies to a matter, which has an industrial application, as an abstract idea cannot be protected. The only recognition for work of a theoretical nature is by publication.

The question of publication by patent, under which the State grants a monopoly of user under certain defined conditions, is one which can only be decided after due consideration of all the interests involved. A provisional protection may be granted for six months in this country for a nominal sum, and this does not entail publication, if the patent is not completed.

In Germany a technical commission examines all patents for novelty and previous publication. In this country the search is confined to English patents of the last fifty years.

The stage at which a patent should be taken out is a matter demanding close attention. If protection is obtained before the details have been worked out sufficiently for the process to be a workable one, its value is correspondingly small. In this respect the English Patent Office offers certain advantages by granting provisional protection. During the subsequent period of six months, the detail of the invention may be embodied by a final specification. The patent of addition is also a help in this direction.

In modern practice it may happen that only part

of the invention is patented and certain details remain secret. Such a step demands special knowledge and involves questions of policy, which will be found to vary in different cases.

The value of such rights to the investigator is difficult to determine. This may depend upon other considerations than that of the importance of the research. Utility is a matter of chief concern, and is a necessary qualification from the legal standpoint.

Facilities for Research in this Country.—These have not been generally available in the past, and it may be argued that this has greatly impeded research in this country. Many of the provincial universities now advertise facilities for research, and the Royal Society and the Chemical Society have at their disposal limited funds, which they disburse by way of grants, prizes, scholarships, etc. Research is also conducted at such institutions as the National Physical Laboratory, the Royal Institution and certain other research stations.

Some of the scientific and technical societies form committees to determine certain points by investigation. For instance, the Institute of Gas Engineers has appointed a Gas Heating Committee, which reports from time to time (see *J. Gas Lighting*, 1910, 2, 810), and the Institute of Metals has dealt with the corrosion of metals and other problems.

The Government offices have also from time to time appointed committees to deal with points, which more or less involve chemical investigation (see *Times Eng. Sup.*, September 21st, 1910). The publications of the Bureau of Mines at Washington, U.S.A., dealing with technical researches and progress are also of considerable importance.

Since the war, many trades have considered research and collectively set up central stations

where problems of common utility can be considered. Only the future can determine the aid this will bring to modern industry.

Care will have to be taken that too much reliance is not placed upon these trade research stations. In many directions they can never replace actual works investigation; nor is this advisable. Success will still come to those concerns who are fully organised on scientific lines right through the works, and those who supplement central research by works research will in the long run be the ones who survive. They will secure the advantage of exclusive information on a number of points, which in itself is a sure return for any expenditure that may be made in securing such information.

This movement will be carefully watched by those who consider that the process of research as carried out in the laboratory is only a part of the main utilisation of the principles of scientific research in its true or economic sense.

Such a process of collective investigation, as is covered by the work at central stations, will be useful, or the reverse as it is practical or not. To be the former it must have its origin in the works, where the necessary observations leading to such work can be made. The process only can lead to useful results when the principles of research are utilised for their further investigation.

Some of the more modern universities, as, for example, that of Sheffield, deal in a similar manner with investigation of more or less technical importance. Thus, in the case mentioned, the Applied Science Committee has arranged that any new processes brought forward may be tested in the University on a manufacturing scale, before any number of manufacturers adopt them.

When, therefore, the general question is asked, whether it is advisable for the student or general

chemist to engage in research, the answer must depend upon certain conditions which cover his training and knowledge of chemistry, natural adaptability, and facility for engaging in such work. The opportunity and time for conducting such investigation may generally be met with even when the operator is engaged in practical work.

The beginner must also determine how far he is able to conform to certain conditions before attempting such work. Given favourable circumstances, much will depend upon the nature of the proposed investigation. In some cases the chances of success are possibly more satisfactory when this work is carried out in one of the recognised colleges, but (according to Gore) only if the professor is an initiator, and if he can actually engage in the same with the student.

On the other hand, it is certain that many successful investigators have not worked under these conditions, and evidence can be advanced which indicates that, in the majority of cases, industrial research can hardly be expected to originate in the college, for it often owes its origin to observations made under practical working conditions.

In many cases, as in the electro-chemical and other modern industries, which owe their existence to research, investigation has been carried on by certain industrial organisations on a scale which could not be undertaken under our present college system. The search for the main and contributory causes which give rise to useful phenomena is too complicated in its nature for it to be undertaken away from the works.

Future of Research.—Considering the amount of research that is carried out by independent investigators, the contention that this may be best carried out in the college or university has not been proved.

At the same time, much research requires the aid of complicated apparatus, and this may be conducted at such institutions or central trade laboratories, but a certain section of it must remain outside the range of the college programme and altogether beyond its financial means. It may, therefore, be necessary to reconsider the available facilities offered for such research work in the institutions of this country, and to determine their natural limitations and scope, and possibly to secure conditions of working, which will facilitate a further advance in the required direction.

In the meantime it is certain that an extraordinary advance has taken place during the last decade in this country in the facilities for research, and that this is making itself felt in many of our principal industries.

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Much time will be saved if information is given—as it can be given—of the basic principle upon which knowledge rests.

It is held, therefore, that the path of future progress is best indicated by a careful consideration of the requirements of the practical man; that, although a great step was taken when the Heuristic method was put into practice, a further step is necessary before the training of students can be considered to be satisfactory. This step calls for the considered opinion of all those, who are engaged in practical work, and the co-ordination of the whole activities of chemistry. As knowledge of the things of industry advances, it must be altered to meet altered conditions, and correspondingly improved. The student must feel that, although he is taking part in a sectional activity, this is thoroughly up to date; not up to date in one direction only and incomplete in others.

It is not sufficient that an observer shall have a considerable knowledge of what has already been learned in his special branch of science, it is necessary that he shall have all available information about the underlying principles and methods adopted when the knowledge was obtained. The latter is of more importance than the former, yet in many cases it is passed by with a mere reference, or else disregarded.

The practice of the college must conform to and agree with that of the modern works. It must not be a practice, which is not met with in the works. In the setting up of a somewhat false idea as to what practice is, the college course has failed to give the best results. The knowledge of what is practical must be gained in the world of practical things.

Scheme of Training.—A scheme similar to that indicated would naturally include a knowledge of

imbued with the importance of knowledge obtained by observation, that his system virtually suppressed the corresponding use of deduction. His great service was in pointing out that all true progress lay in a "graduated and successive induction" where advance proceeded by ordered steps to the highest generalisations.

Modern experience has shown that the Baconian method is too limited, and that progress is best achieved by the continual use of both induction and deduction. Thus Tyndall held "that the real vocation of an investigator like Faraday, consists of the incessant marriage of both." That Boyle was influenced by Bacon's work is generally acknowledged.

Lemery followed in Boyle's footsteps, and also insisted that chemistry was a science of observation. He suggested the natural division of this science into its organic and inorganic branches. Boerhaave published his "Elementa Chemia" in 1732. This work greatly influenced the thought of the period. The investigations of Priestley and Cavendish, which followed, are too well known to demand more than passing notice. With those of Lavoisier, Dalton, Berzelius, Prout, and Davy, they bring us to the early days of the nineteenth century, when Nicholson and Carlisle first decomposed water by the aid of the voltaic pile. This last observation received great attention, deepening the rising interest in this progressive science, and materially assisting its general development.

Thus a rapid advance in chemistry followed the recognition of the unique value of investigation by experiment. Boyle's suggestion and its definite acceptance as the only reasonable source of knowledge of natural phenomena has led up to the commanding position which modern chemistry and the experimental sciences occupy to-day.

By an examination of the developments, which